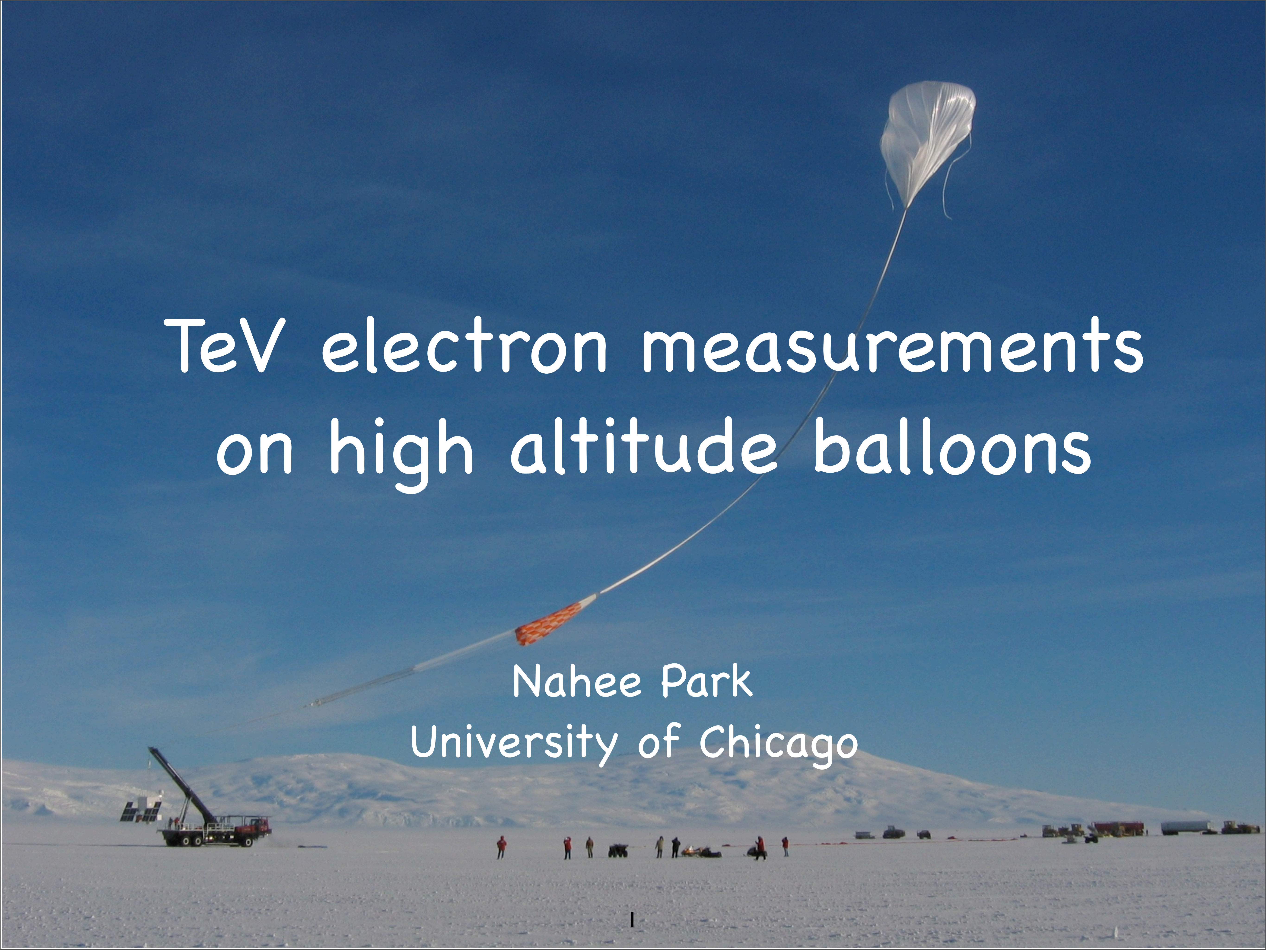


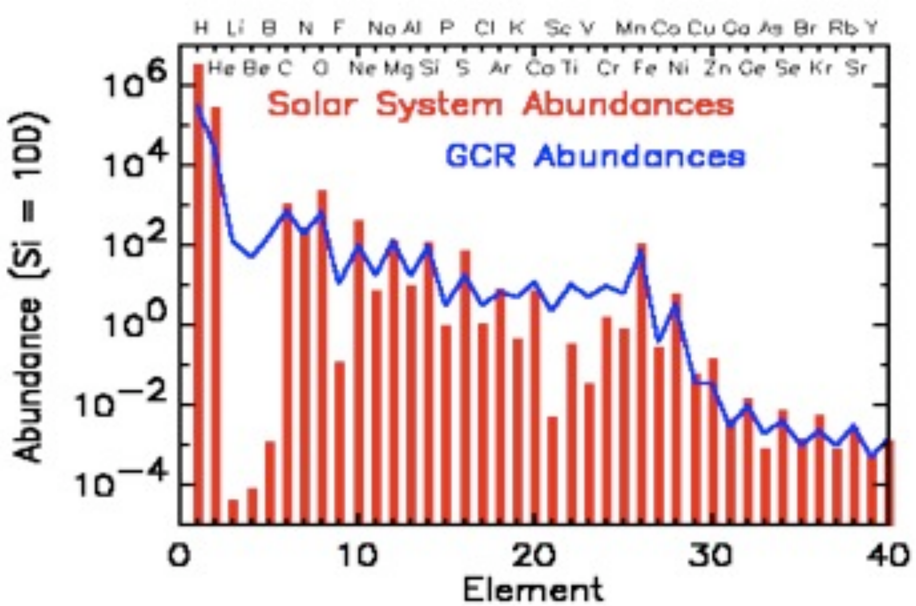
TeV electron measurements on high altitude balloons

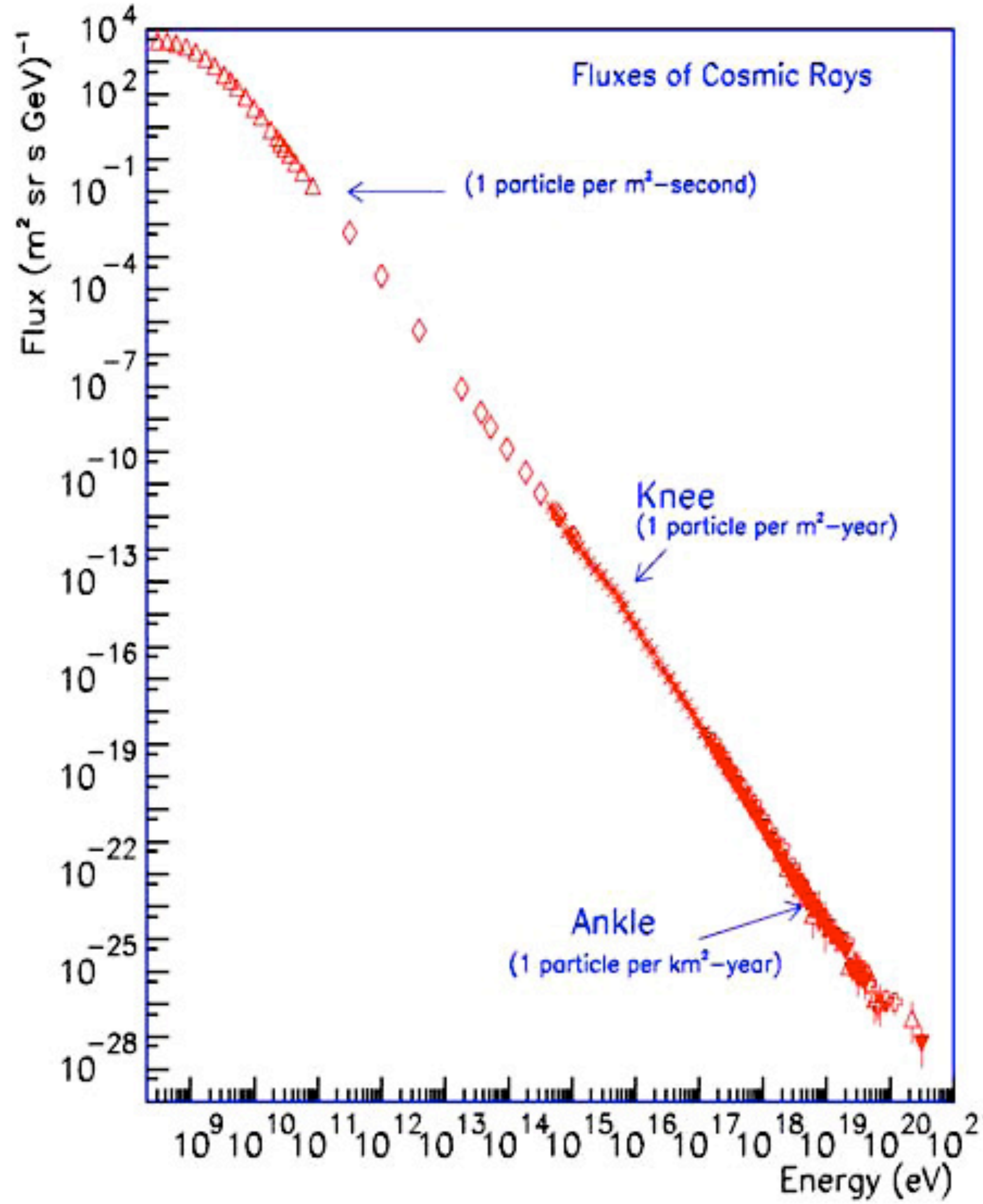
Nahee Park
University of Chicago

Cosmic rays (1)

☐ Properties

- Spectrum following the power-law distribution over wide energy range
- Composition
  - ~ 88% of proton,
    ~ 11 % of heavier elements
    and small amount of electron (<1%)



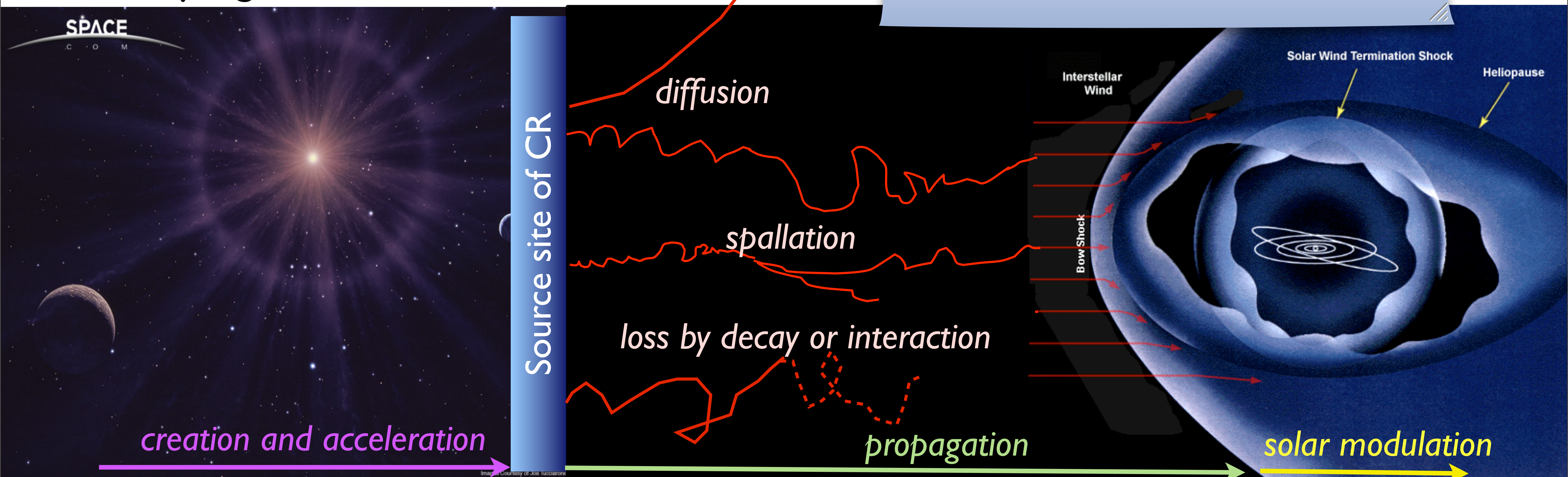


Cosmic rays (2)

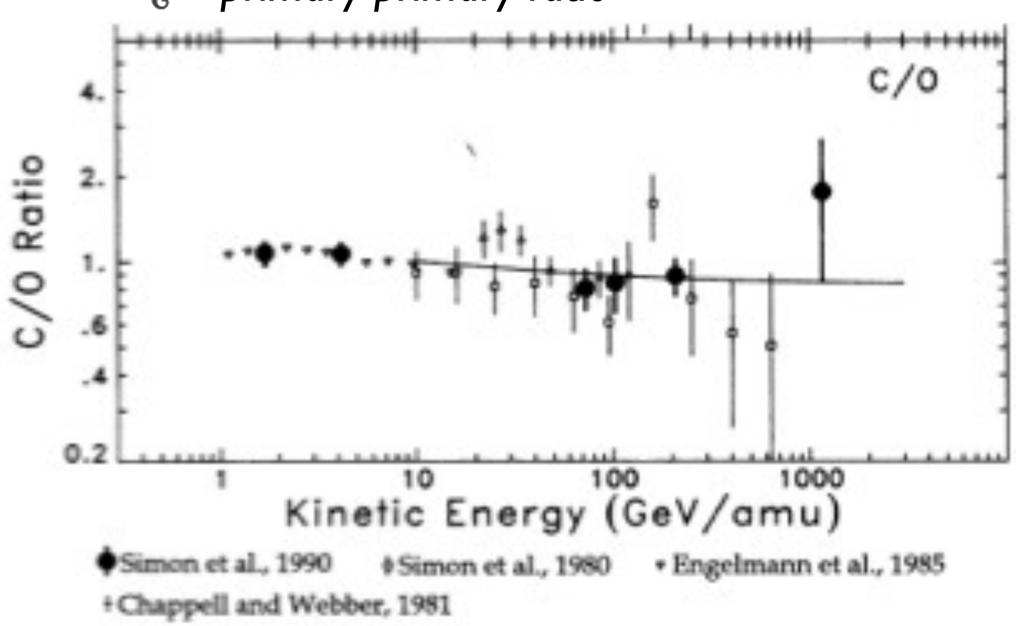
typical grammage of ISM : <~ 2mg/cm2

cf. CREAM measurement : TeV/n : ~ 1 g/cm2

☐ Propagation of CR nuclei

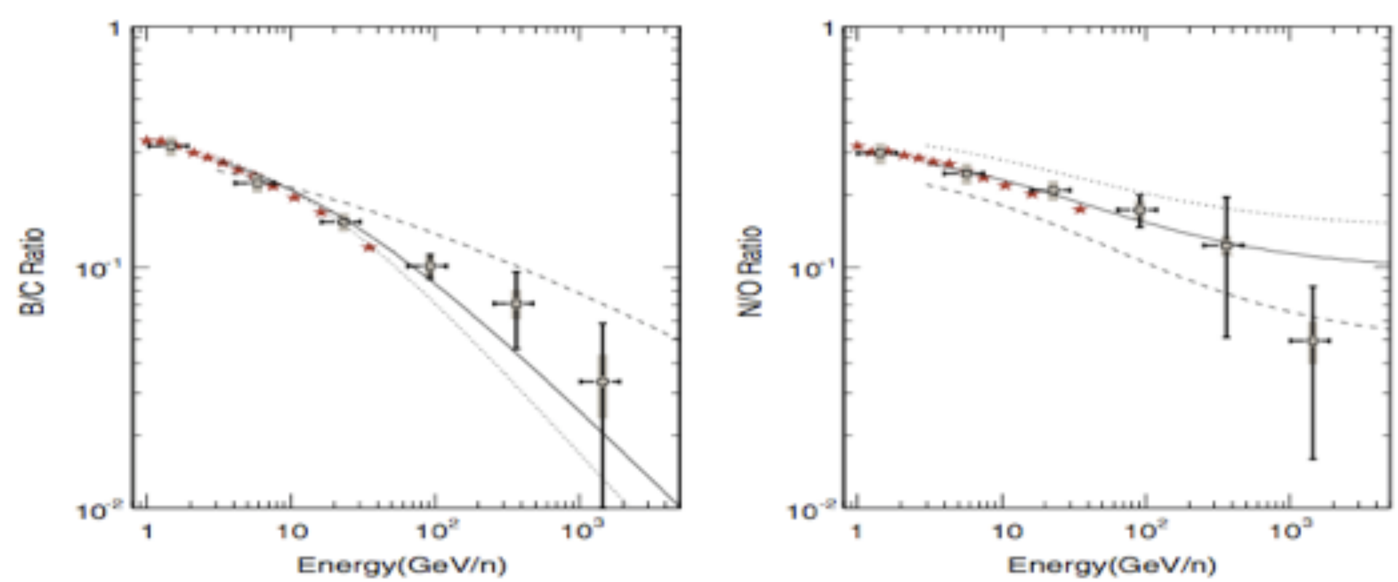


- *primary-primary ratio*



Swordy et al., ApJ 349, 625-633, 1990

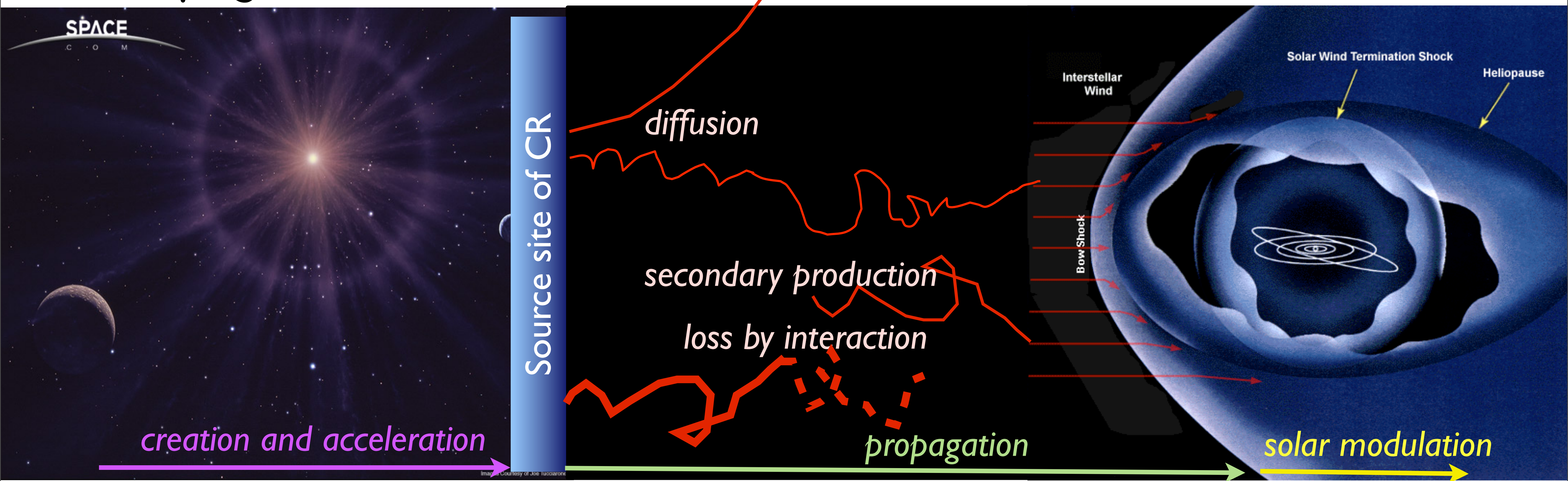
- *primary-secondary ratio*



Ahn et al., APh 30, 133-141, 2008

Cosmic-ray electron (1)

☐ Propagation of CR electron



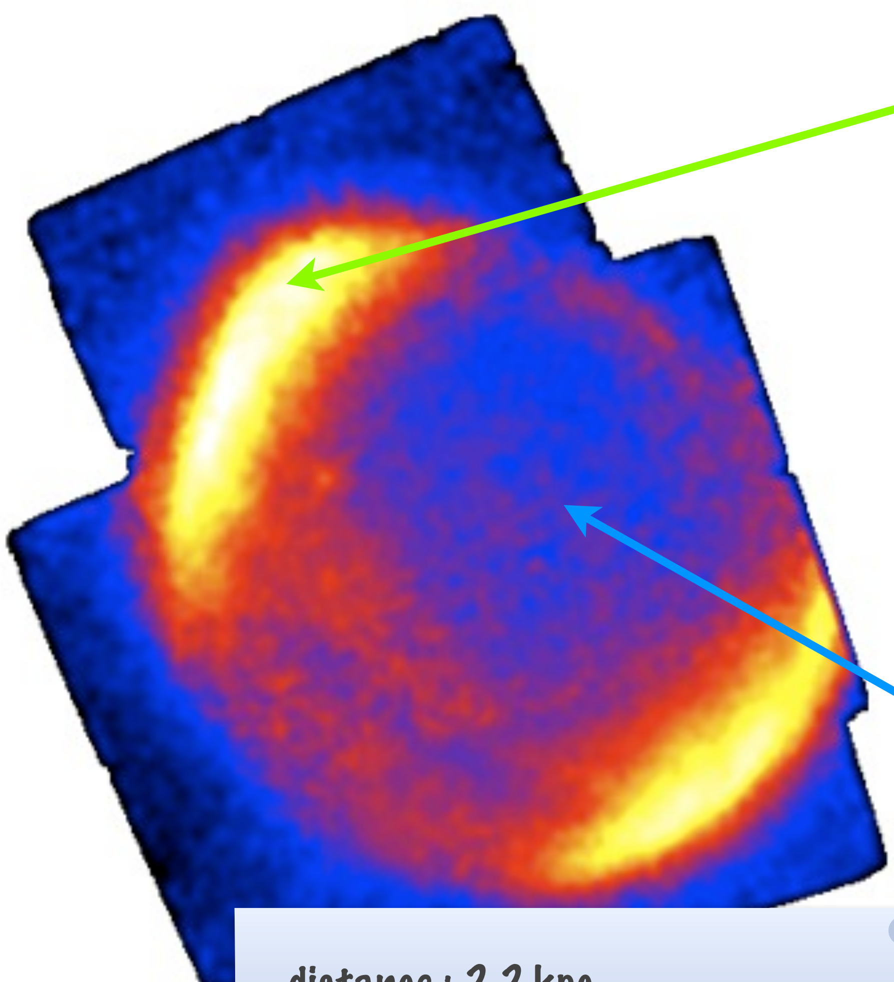
- High energy electron lose its energy via synchrotron radiation and inverse Compton process
- Secondary electron produced in pairs with positron
  - proton - ISM → $\pi^{\pm}$ → $\mu^{\pm}$ → $e^{\pm}$
- $e^{+}/(e^{+} + e^{-})$ faction is small (~ 10 %)
  → Substantial primary electron component

Like GZK cut-off of electron
(at several TeV)

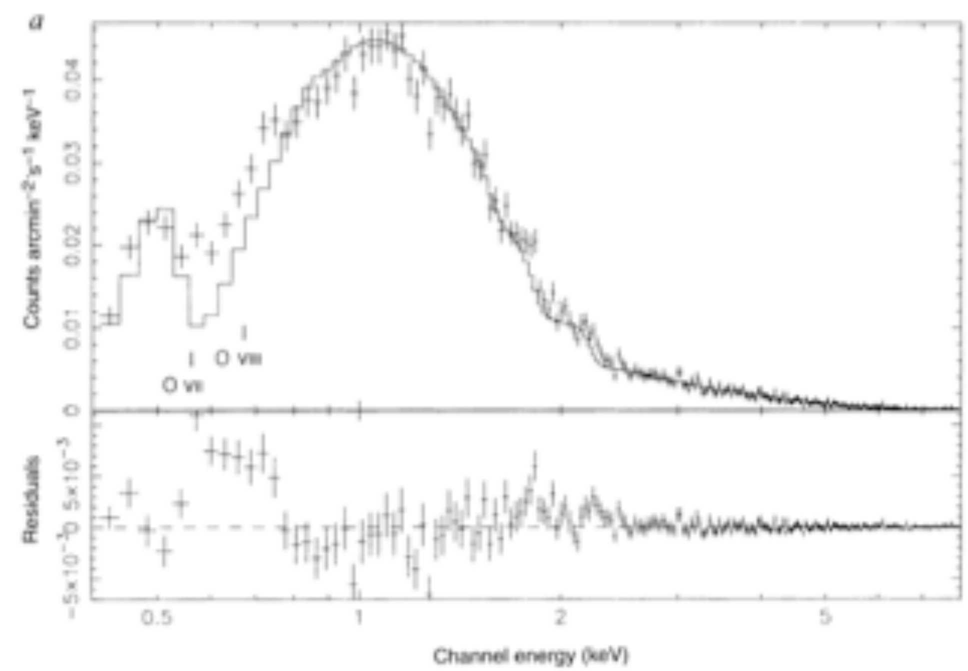
Cosmic-ray electron (2)

☐ Indirect measurement

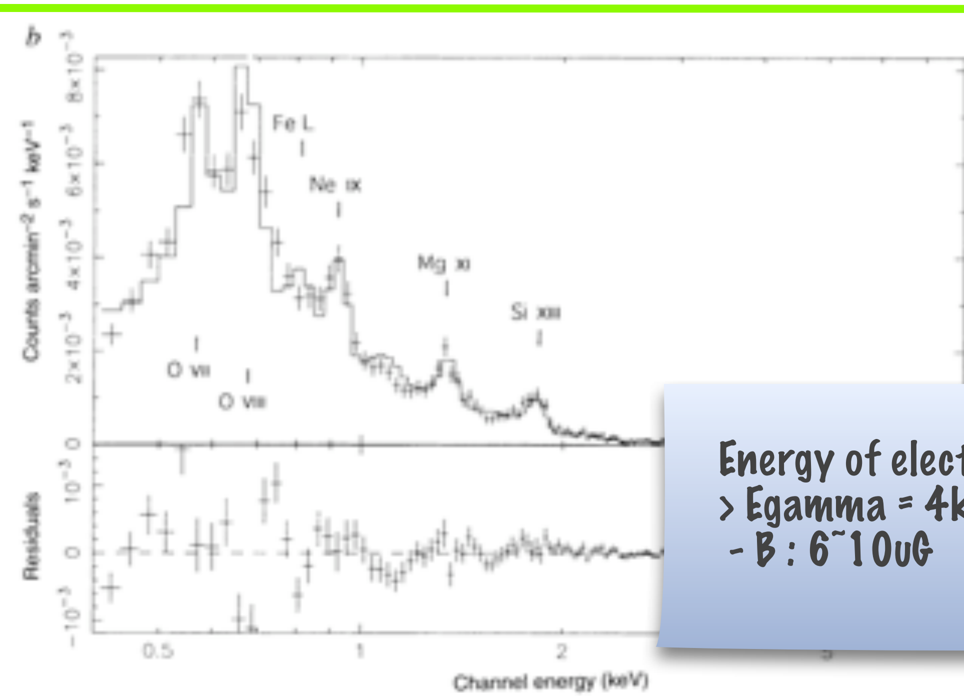
- Strong (indirect) evidence for supernova shock acceleration of galactic CR electrons through observations of non-thermal X-rays and TeV gamma rays from SN remnants.



distance : 2.2 kpc
size : Right Ascension ~ 2 min. / Declination 0.5 degree
diameter : 20 parsecs



Non-thermal emission from rim.
Morphology correlates well between x-ray and radio bands



Thermal emission from core

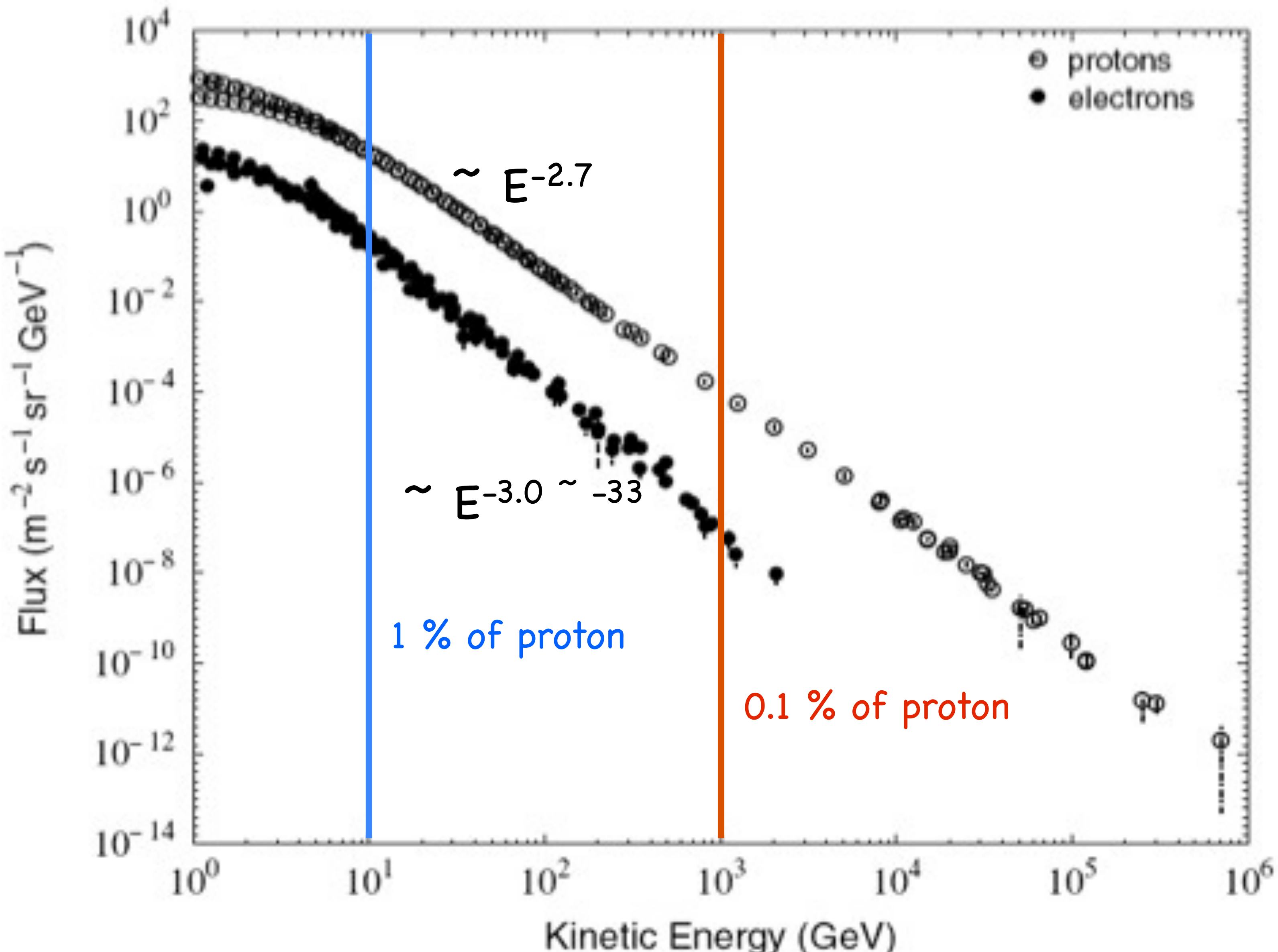
Energy of electron : 100 TeV
> Egamma = 4keV * B/mG * (Ee/10TeV)^2
- B : 6~10uG

Koyama et al., Sci.378, 255-258 (1995)

Cosmic-ray electron (3)

Cosmic ray electron

- ~ 1% of proton intensity at 1 GeV, rapidly decreased than proton
  - Energy loss of high energy electron is proportional to E^2
  - TeV electron horizon : ~ 1 kpc (10^5 yr propagation)
    - Possible local source : Vela, Cygnus loop, Monogem SNRs ...

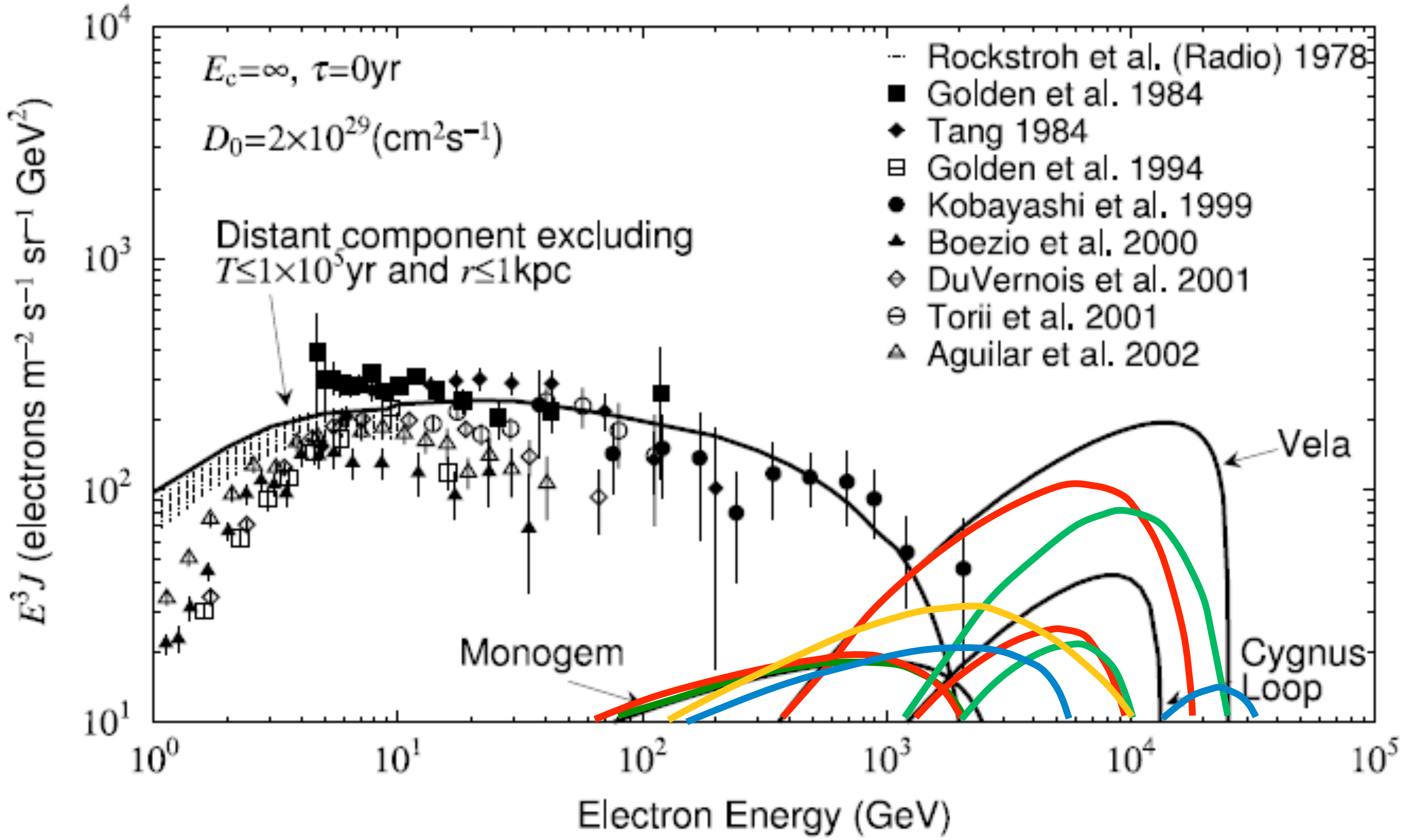


Yoshida, Adv.Sp.Res. 42, 477 (2008)

Cosmic-ray electron (4)

- Measurements and prediction
  - Contribution from SNRs depends on diffusion coefficient, release time, energy cutoff
    - Plenty of parameter space for exploration TeV range can reveal features of nearby sources

Cut-off is shown on this spectrum with out Ecutoff assumption because of high energy electron will lose its energy faster by radiative energy loss process



E_c = 20 TeV, τ = 0 yr, D_o = 2×10^{29} cm²/s

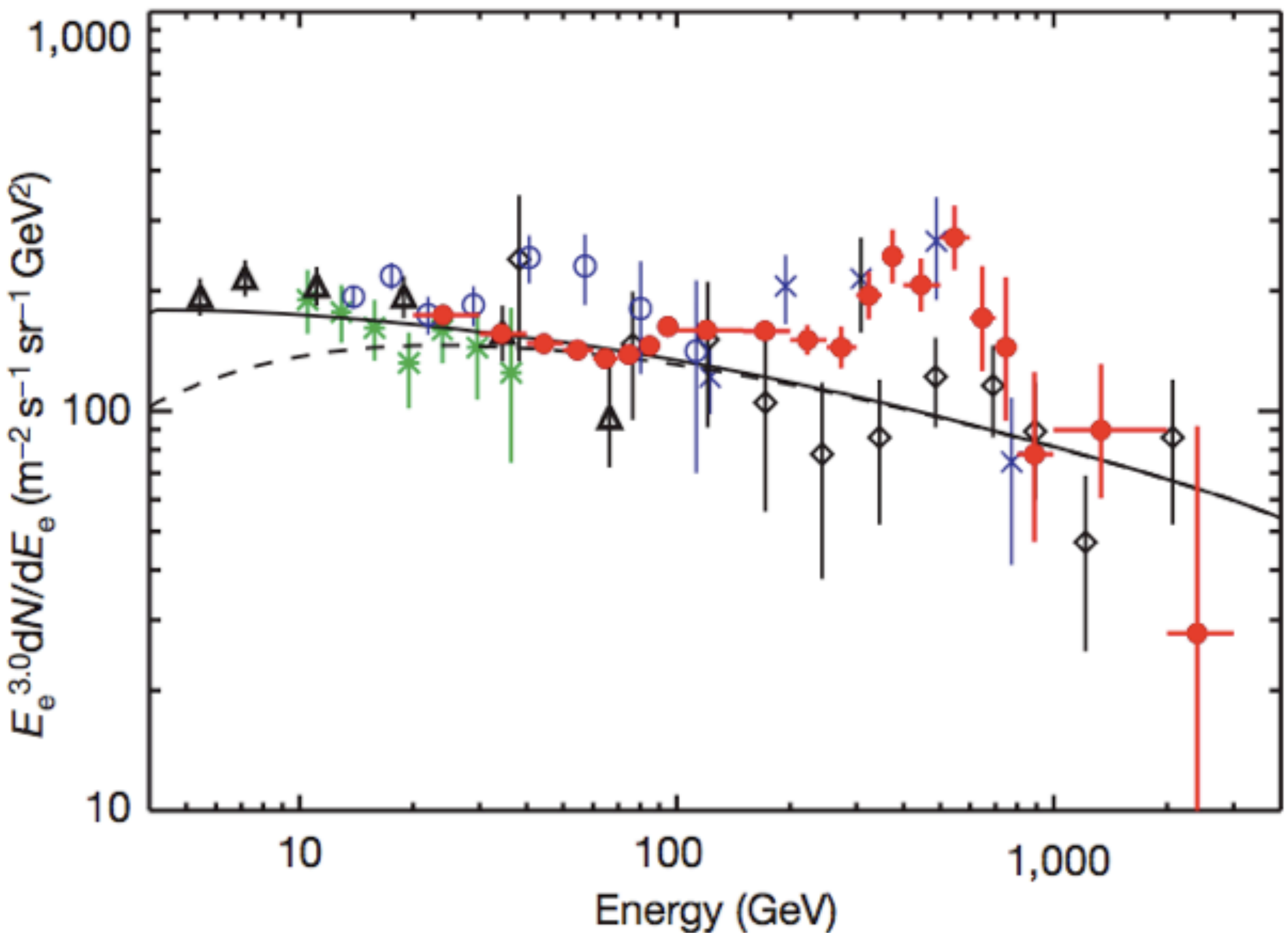
E_c = 20 TeV, τ = 5000 yr, D_o = 2×10^{29} cm²/s

E_c = 20 TeV, τ = 10^4 yr, D_o = 2×10^{29} cm²/s

E_c = 20 TeV, τ = 0-1×10^5 yr, D_o = 2×10^{29} cm²/s

Kobayashi, ApJ. 601, 340 (2004)

- Recent measurements



Other possible signal which could be measured through electron measurement.

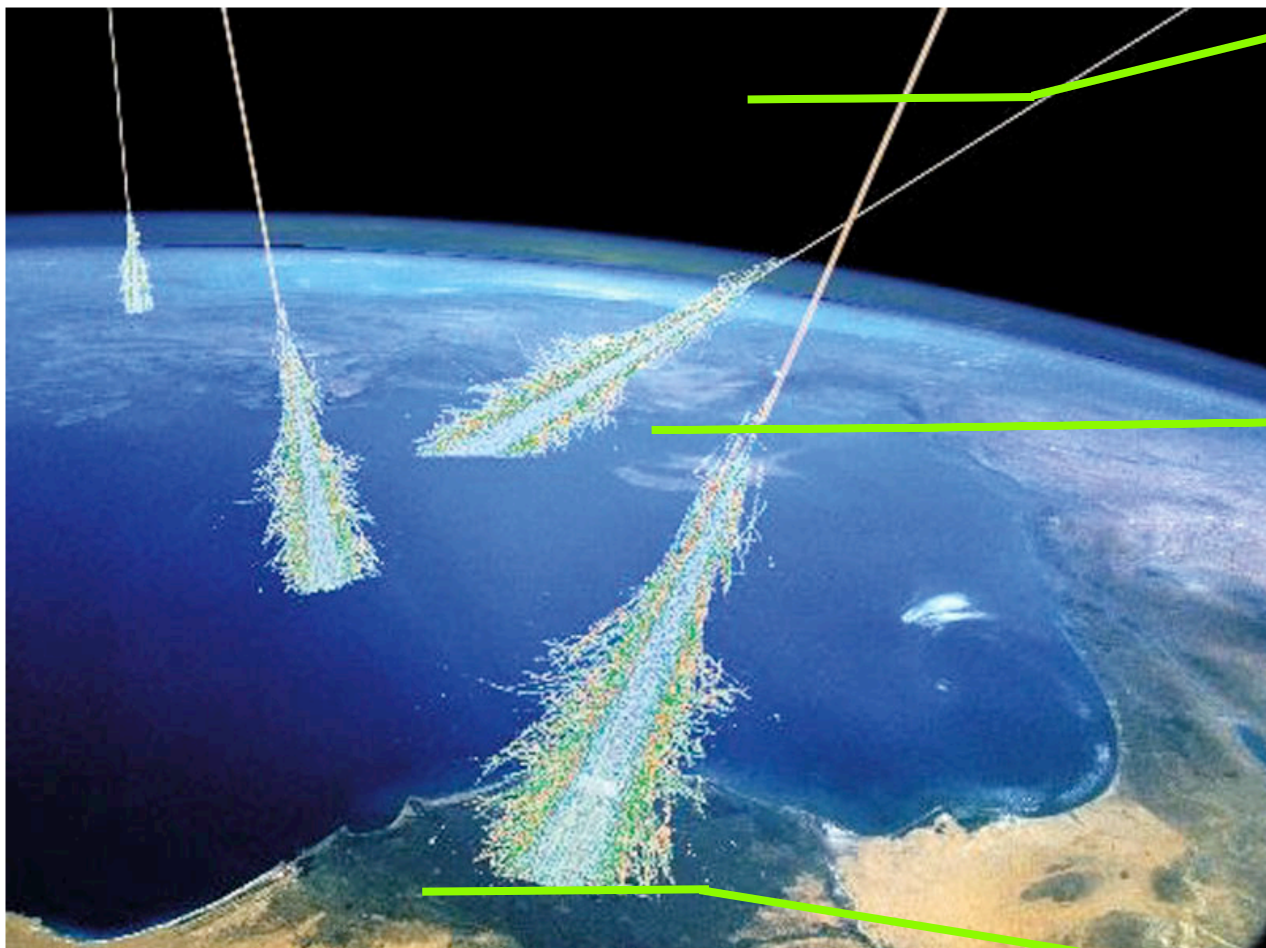
The result may need to be confirmed.

AMS (green stars), BETS (open blue circle), PPB-BETS (blue crosses), HEAT (open black triangles), emulsion chambers (black open diamonds) and ATIC (red filled circle)

Chang et al, Sci. 456, 362-365 (2008)

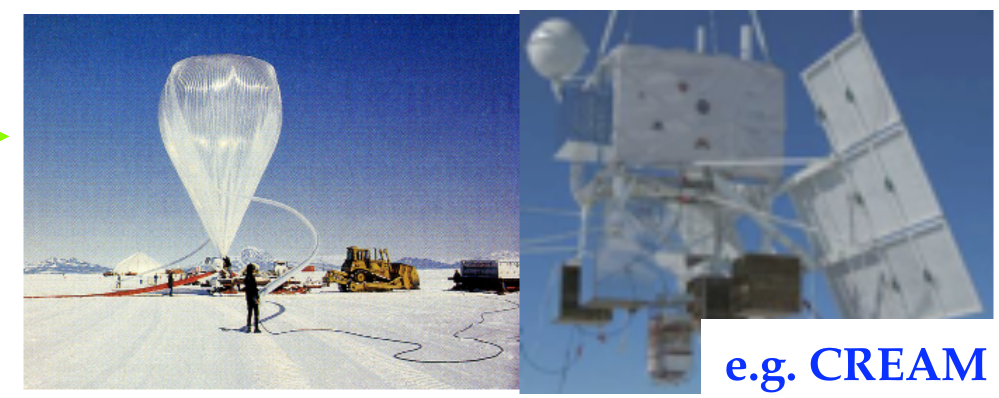
Measurement of Cosmic rays

☐ Measurement of CR at earth

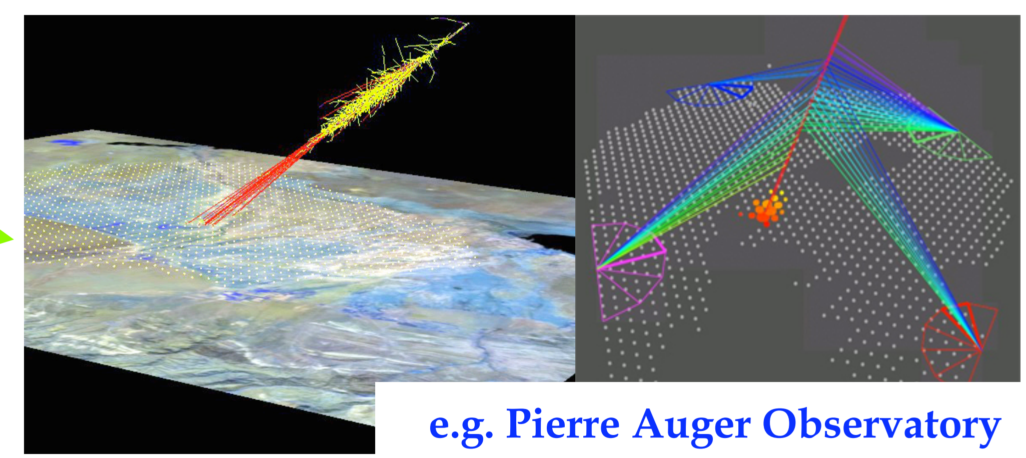

Air showers of cosmic-ray particles incident on the atmosphere


e.g. PAMELA

Space experiments


e.g. CREAM

Balloon experiments in the upper atmosphere

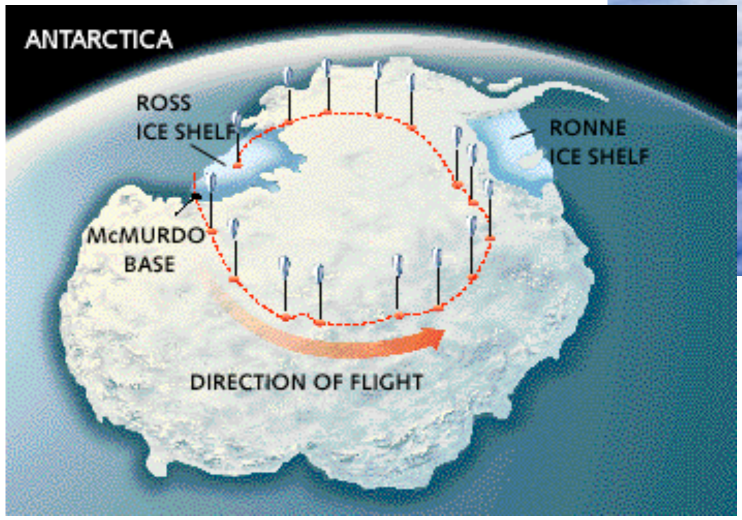

e.g. Pierre Auger Observatory

Ground array experiments

Balloon experiment

Properties of balloon experiment

- Advantage
  - Short preparation time
  - Relatively low cost
  - Recovery of instrument
- Balloon used for the current experiment
  - Long duration balloon (LDB)
    - Altitude : 35 ~ 40 km
    - Duration of flight : 7~15 days (typical)
- Future balloon
  - Ultra long duration balloon (ULDB)
    - Altitude : ~ 35 km
    - Duration of flight : 60 ~ 100 days



Trajectory of TRACER in 2006

CREST experiment

- CREST (Cosmic Ray Electron Synchrotron Telescope)

University of Chicago

S. Wakely, N. Park, D. Müller

Indiana University

C.R. Bower, J. Musser

Northern Kenturcky University

S. Nutter

Penn State University

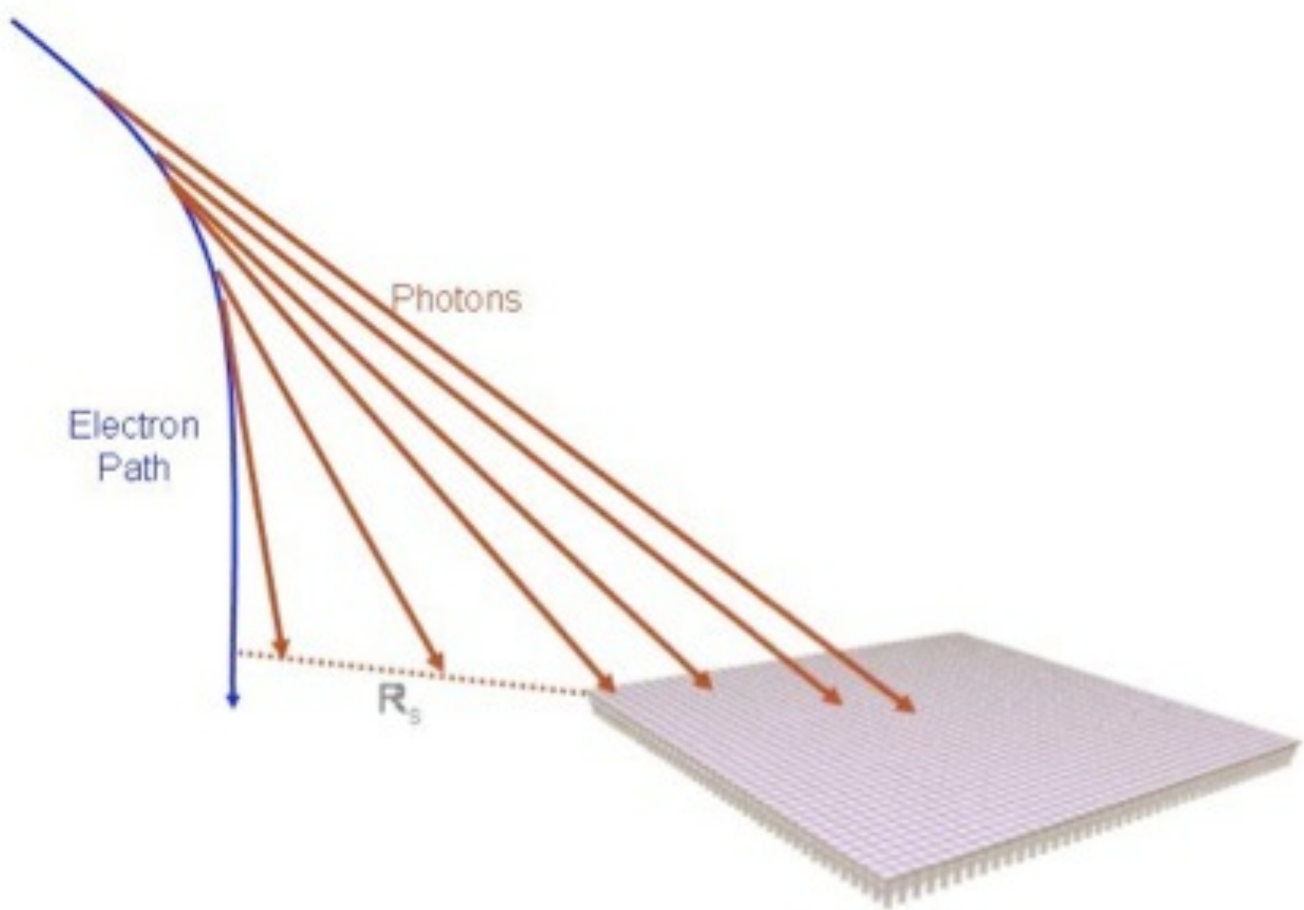
T. Anderson, S. Coutu, M. Geske

University of Michigan

M. Schubnell, G, Tarlé, A. Yagi, J. Gennaro

CREST experiment

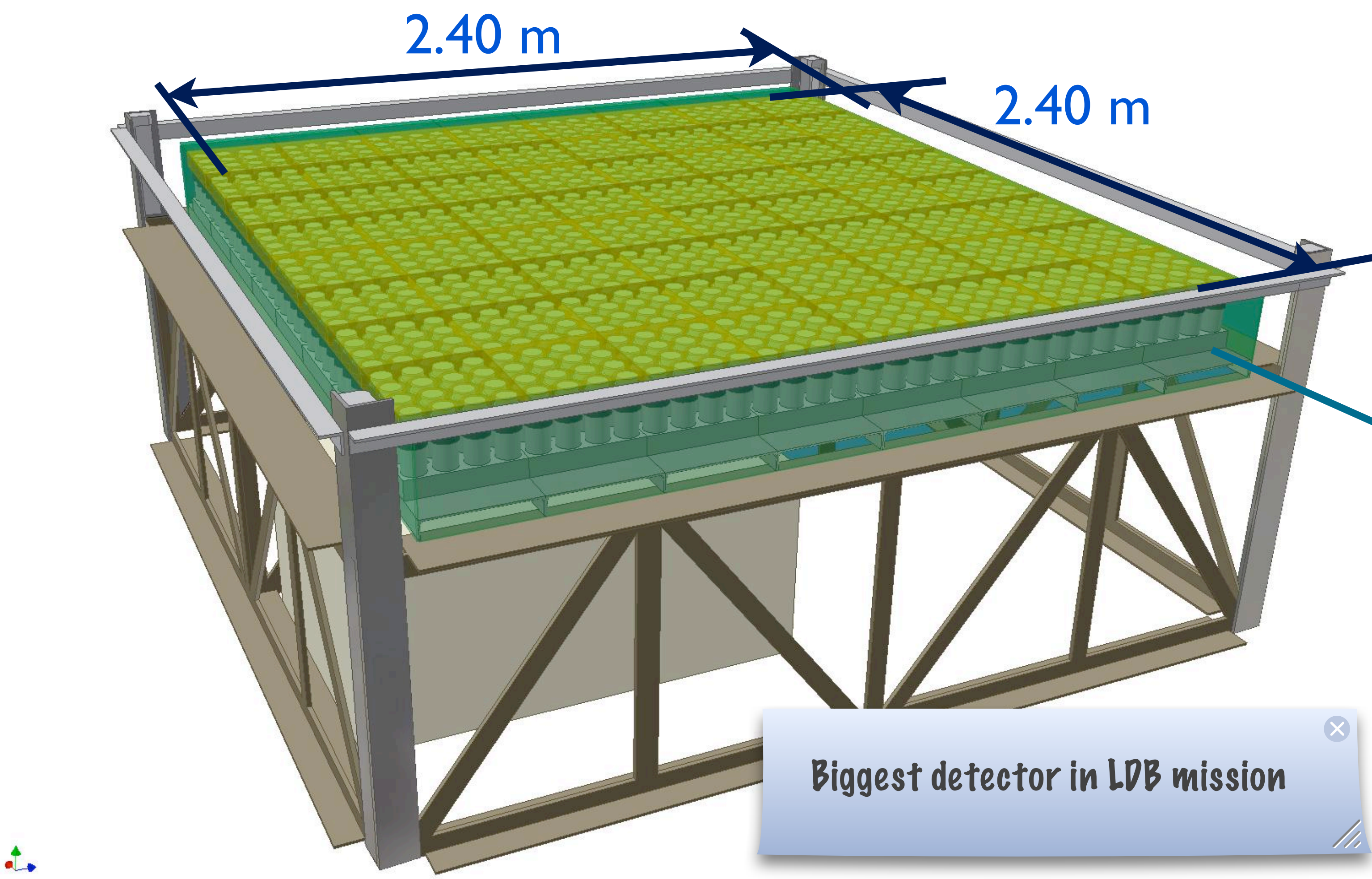
- CREST (Cosmic Ray Electron Synchrotron Telescope)
  - Scientific goal
    - Measurement of high energy electrons (>TeV)
  - Detect synchrotron radiation of primary electron as it passes through Earth's magnetic field
    - Effective area of instrument increases greatly
    - Rejection of proton signal
  - Balloon experiment designed for long duration flight at Antarctica



CREST experiment

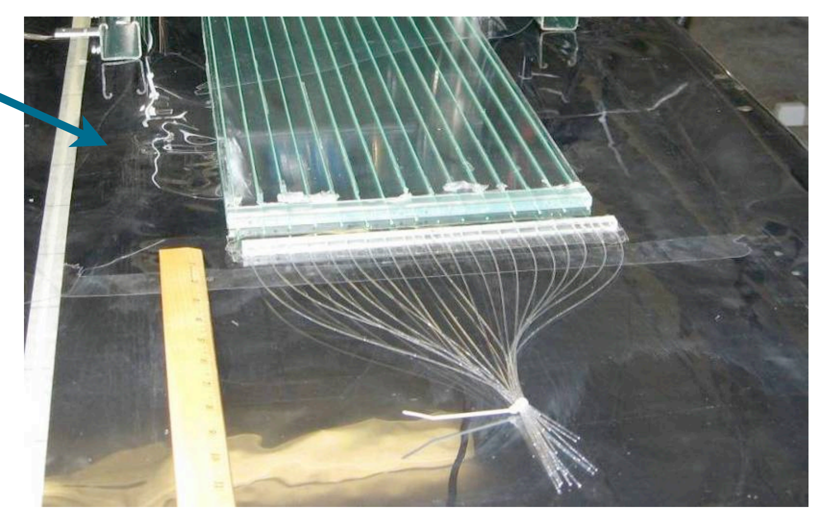
Detector

- Crystal array
  - 1024 units of BaF_2 crystal + PMT
  - Detector area : 5.8 m^2 (2.0 m^2 in crystals only)
- Veto counter
  - Hermetic plastic scintillator



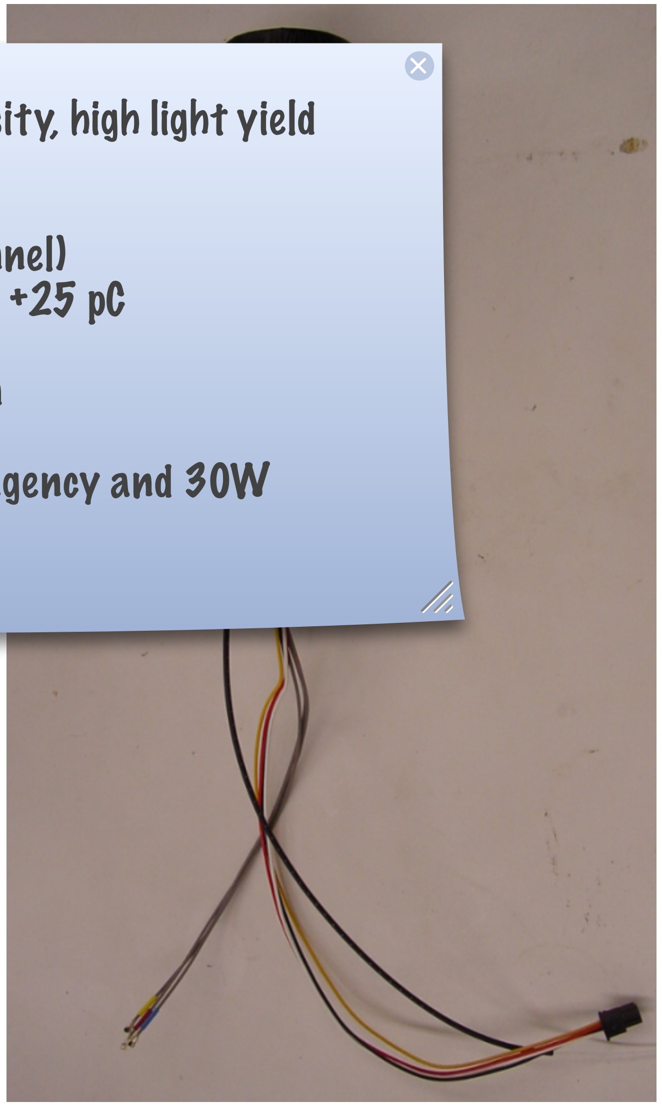
Biggest detector in LDB mission

Veto paddle : MINOS design



Crystal array

- BaF2 crystal (2 cm thickness, 5 cm diameter)
  - Fast component (Timing)
    - 15 %, 0.6 ~ 0.8 nsec decay time
  - Slow component (Energy)
    - 85%, 630 nsec decay time



Crystal (BaF2) : high density, high light yield

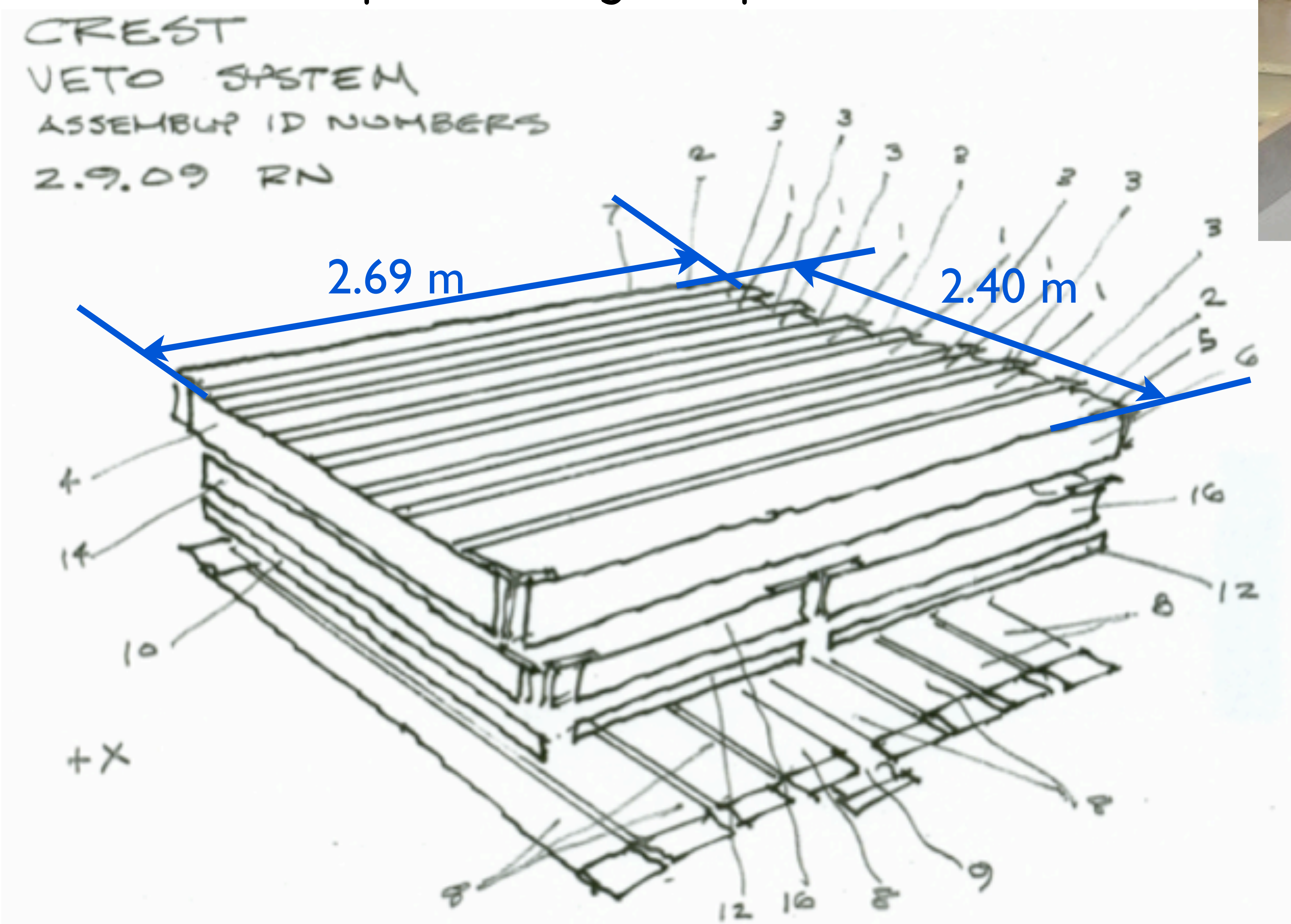
VA chip
> ~73.6mW (2.3mW/channel)
> Dynamic range -35 pC ~ +25 pC

Total power consumption
~790 W
(including 15W of contingency and 30W heater)

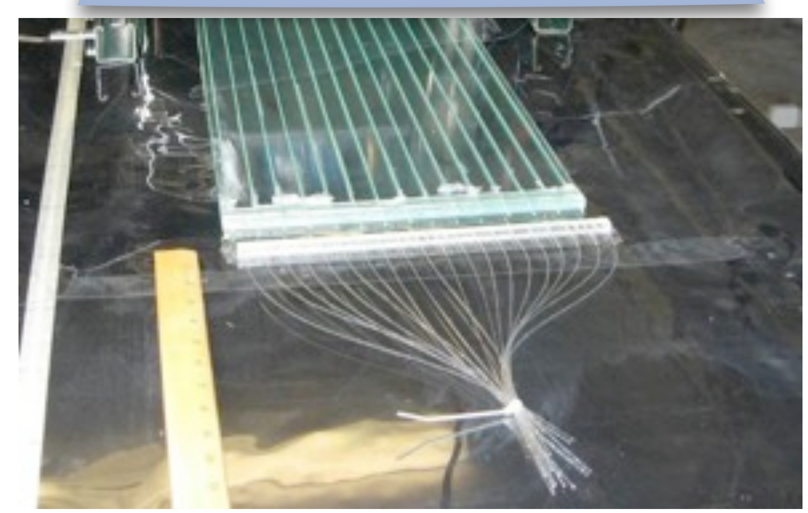
- Readout
  - Hamamatsu R7724 CW Custom 2" PMT
    - Cockroft-Walton low power base (30 mW)
    - Individual HV control
    - Calibration with optical fiber and pulser signal
  - VA32_HDR11 ASIC chip
    - 32 channels low-noise/low power charge sensitive preamplifier-shaper circuit
    - Simultaneous sample, hold, multiplexed analogue readout
    - Calibration function

Veto system

- Veto system for the CREST
  - 4π coverage
  - Eljen EJ-200 scintillator with embedded green waveshifting fibers (Kuraray Y-11M).
  - Muon tests : ~ 40 p.e. (summed response)
    - Flat response along the paddle



Built by Penn state & NKU



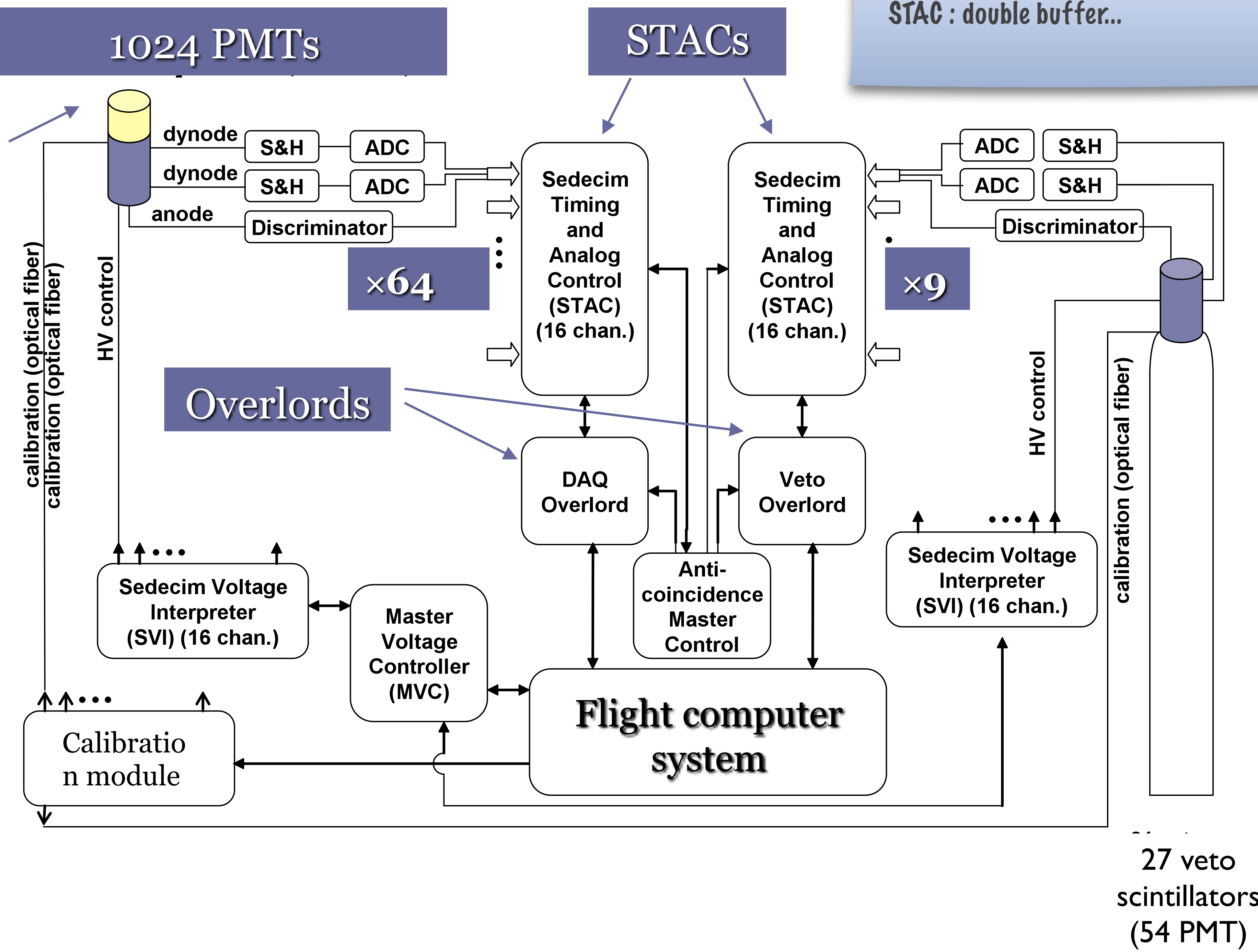
Ends milled to mate cleanly. 15 fibers in 30 cm.
Clear fiber light guides allow flexible positioning

Data acquisition system

- "Triggerless" DAQ system

Continuous streaming of data to decision tree. (ring buffer)
STAC : double buffer...

Dynamic range obtained through multiple signal taps



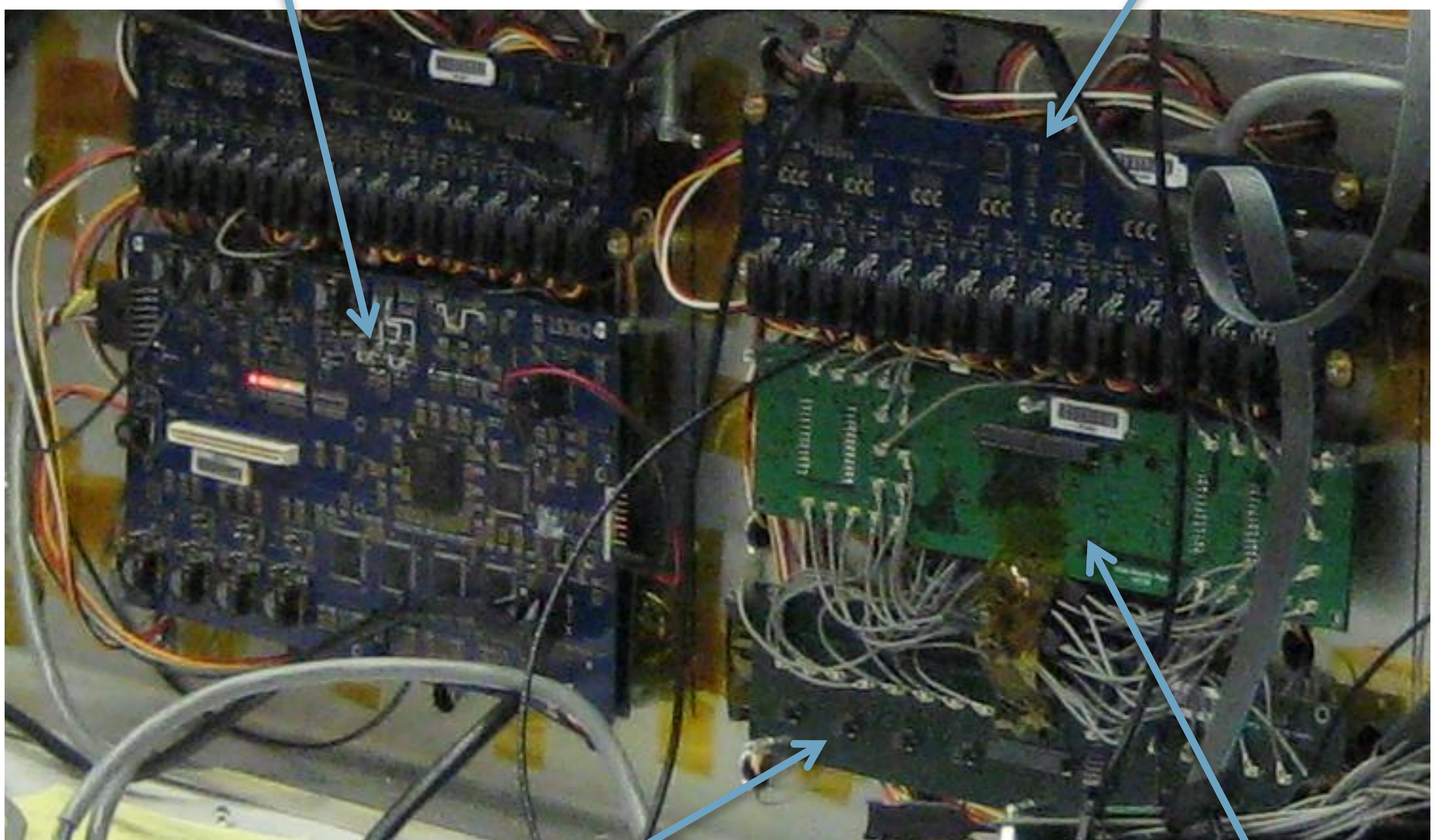
All timing information is always recorded

Electronics (1)

Contains 14 bit ADC chips
Communicate with overload
Control the front-end system

SVI board

Provide the control voltage
for HV control of PMT



Discriminator board

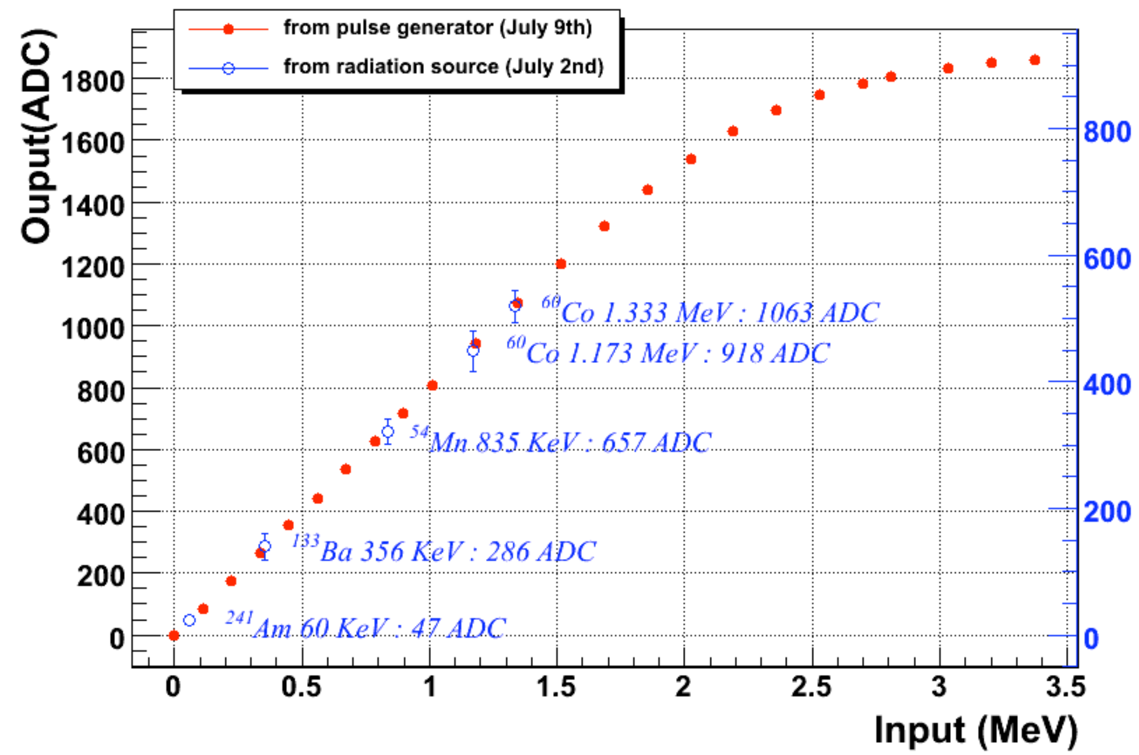
16 channel discriminator

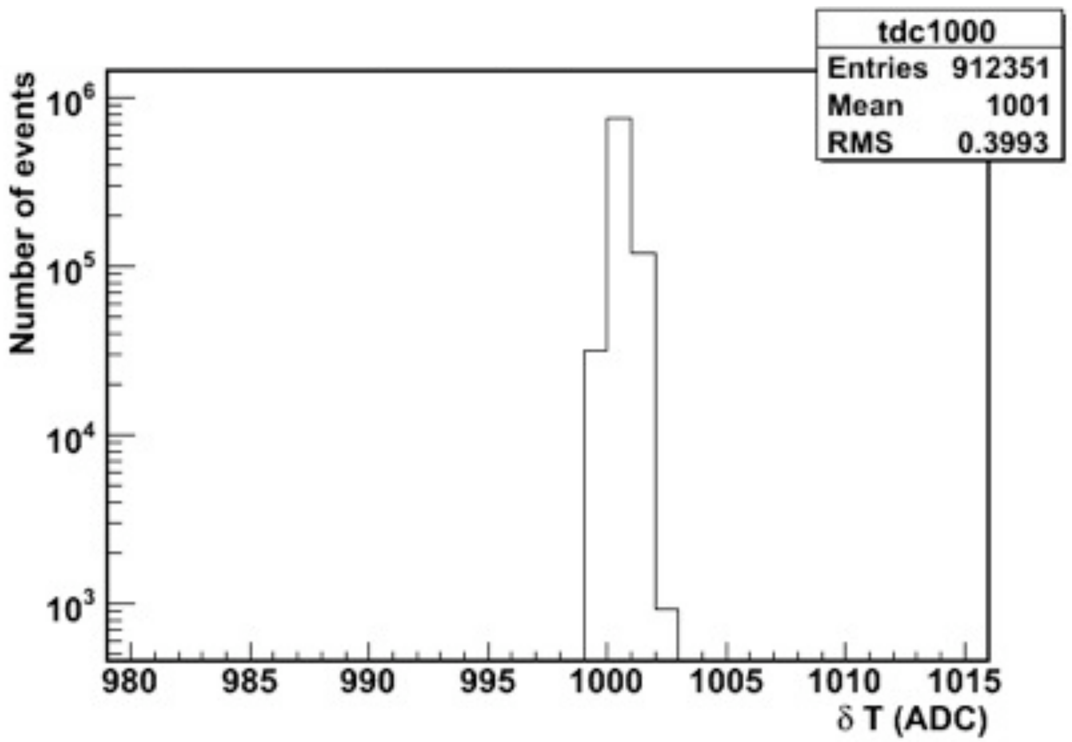
VA board

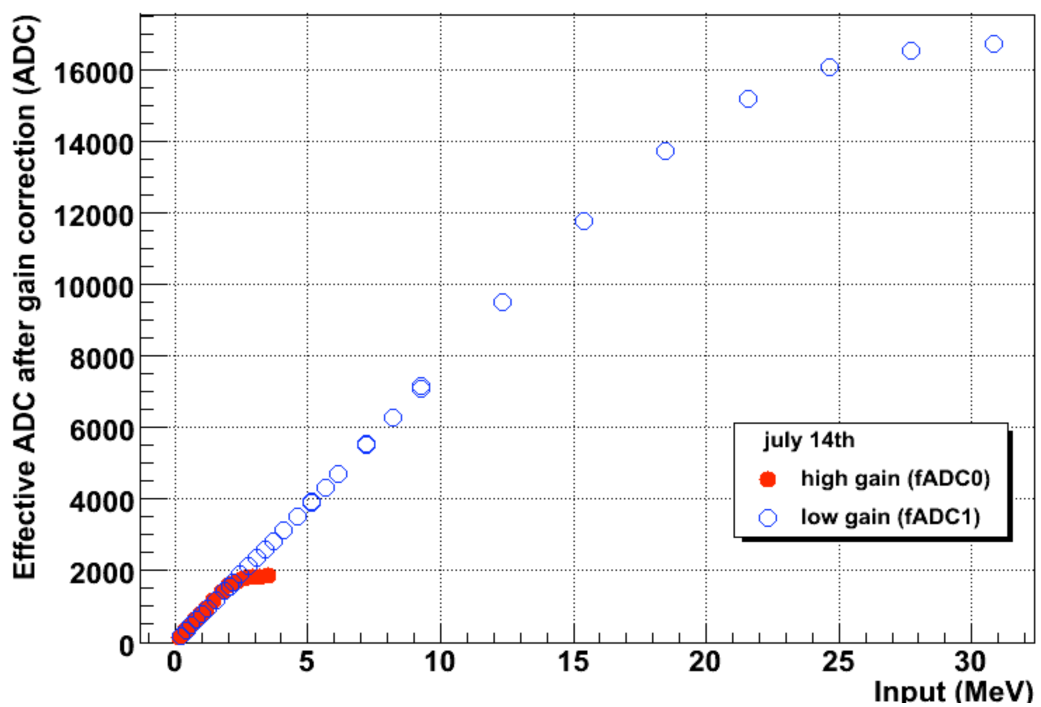
Contains the front-end electronics
2 VA chips – one for each gain

Electronics (2)

- Test
  - TDC resolution
    - 1 σ : ~ 400 psec
      - Electronics only, measured with pulse generator input
  - ADC
    - Dynamic range : ~ 1:900
      - good linearity up to ~ 25 MeV
        - High gain (up to ~ 2.5 MeV)
        - Low gain (up to ~ 25 MeV)







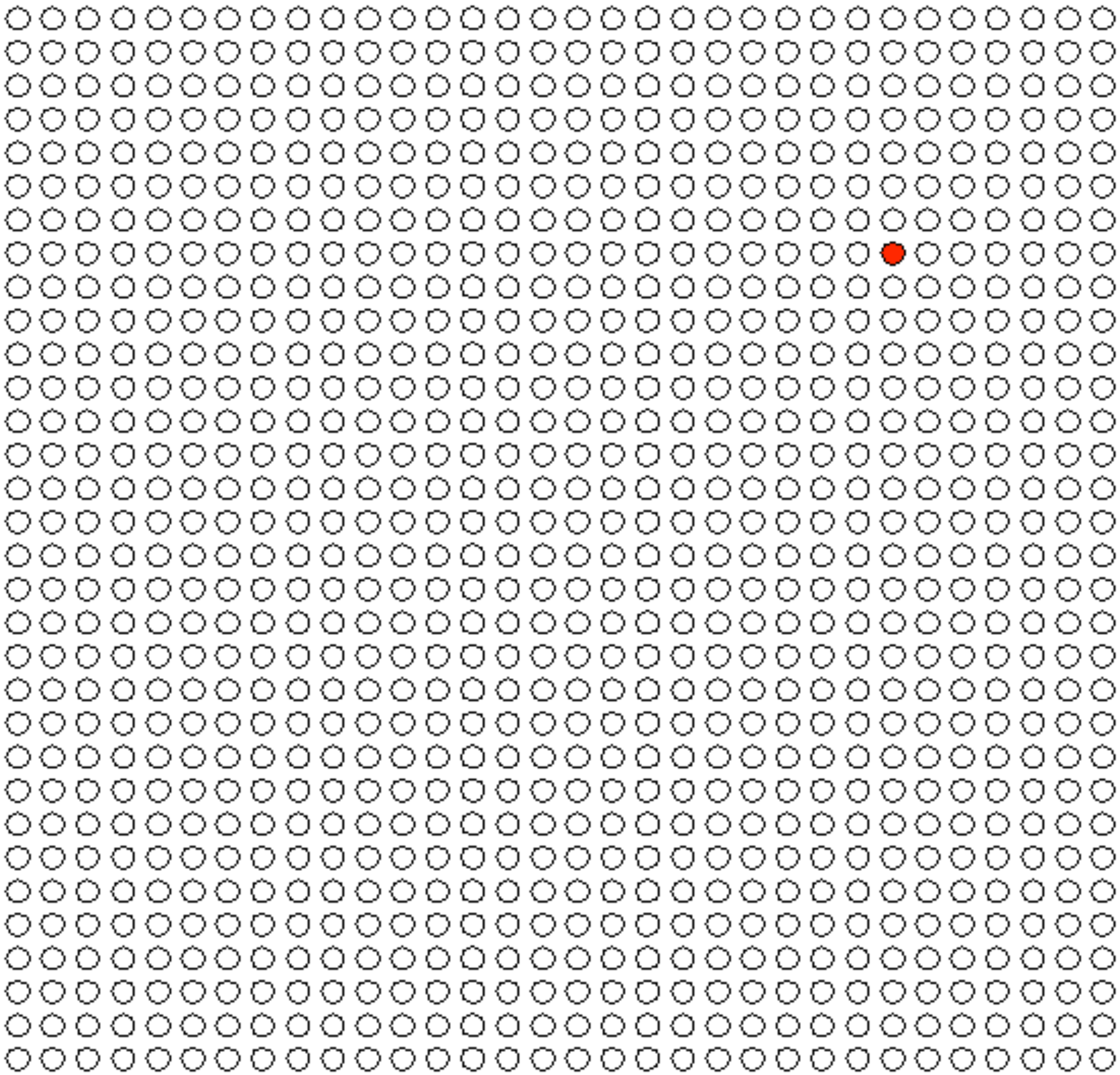
Signal and Background

☐ Signal and background

- Signal : electron events appear as a line of photons arriving nearly simultaneously
  - Strong atmospheric absorption below ~ 30 keV
  - Properties of synchrotron radiation depend on geomagnetic field
    - *Study about the propagation within geomagnetic field is needed.*

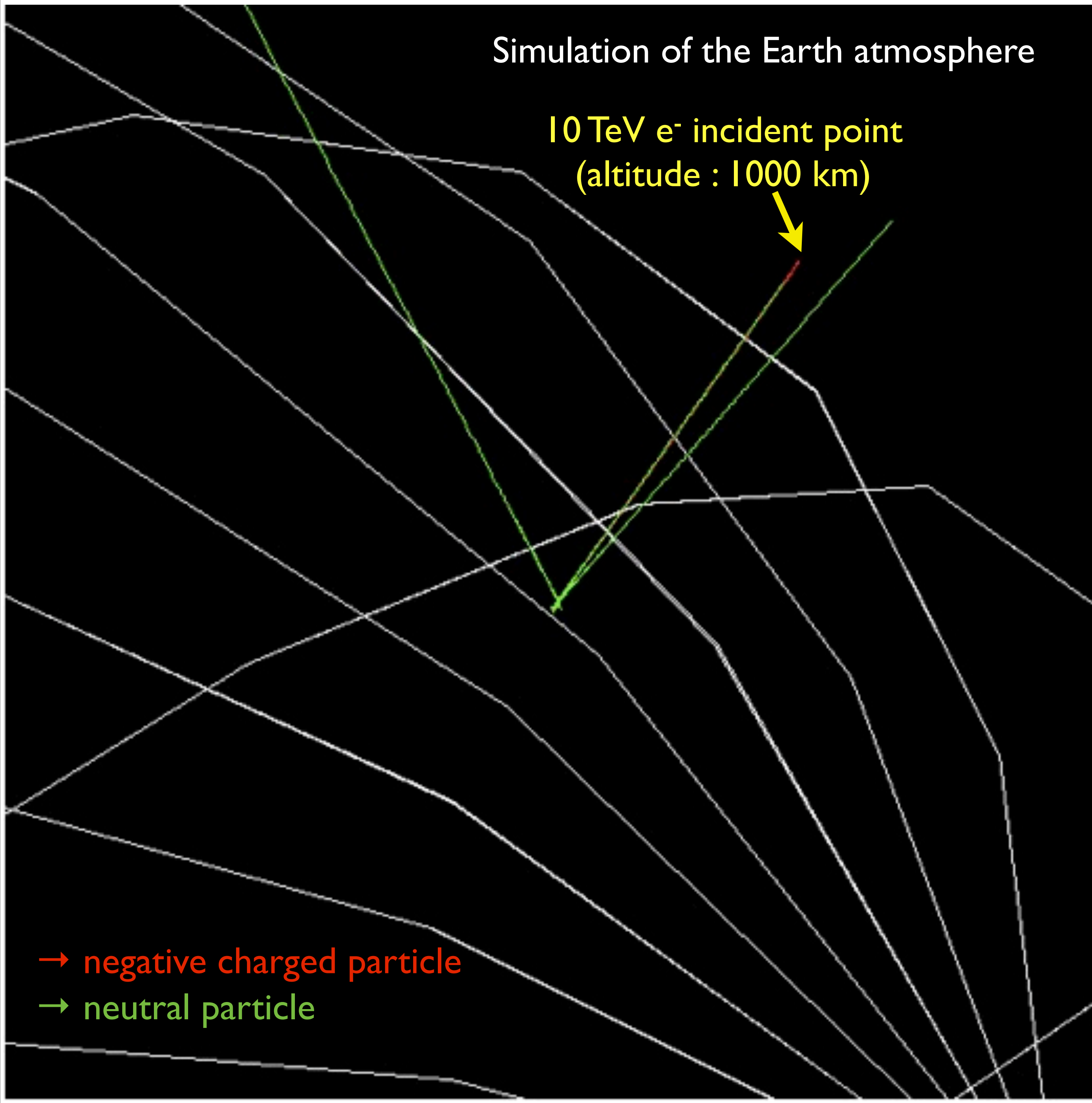
- Background
  - Random coincidence x-ray photons
    - *Cosmic and CR shower produced x-ray*
    - *Depends on the altitude (grammage) and geomagnetic latitude (rigidity cutoff)*
  - Interactions in the detector and frame

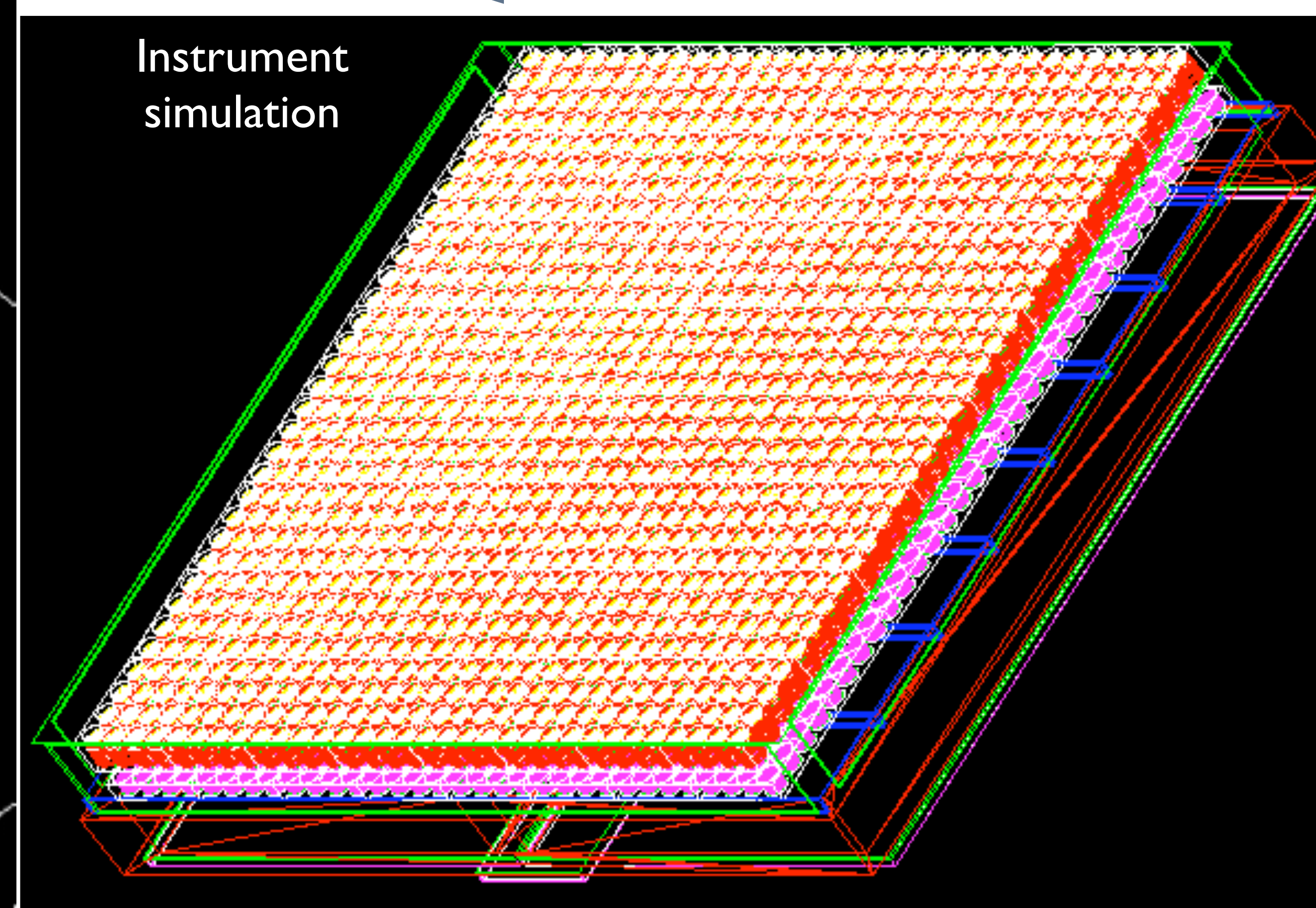
Simulation Study (1)



Simulation Study (2)

- Event simulations
  - Propagation of the primary electron within the atmosphere
  - Instrument response



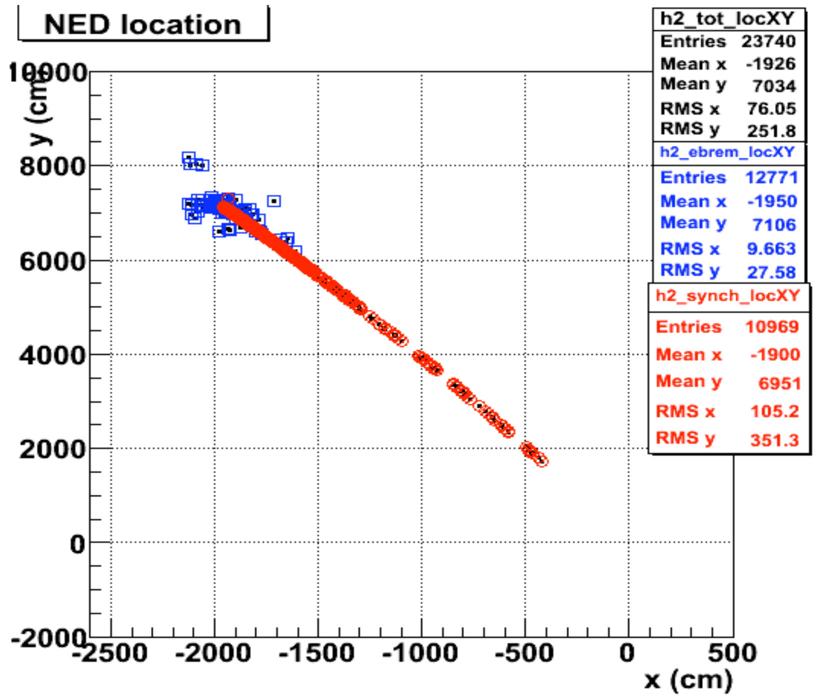


Simulation Study (3)

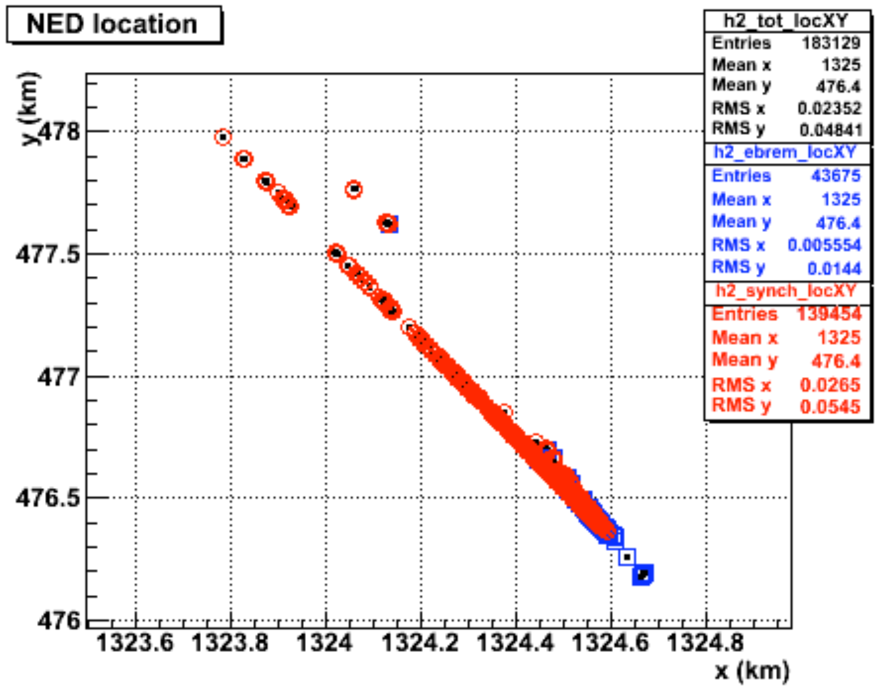
1. Plot angle Vs. Number of survived gammas
2. Plot the incident electron energy Vs. number of survived gammas (isotropic case)
3. Plot of the incident electron energy Vs. average synch gamma energy

Simulation study for the signal

- Distribution of gammas from 10 TeV electron with/without angle

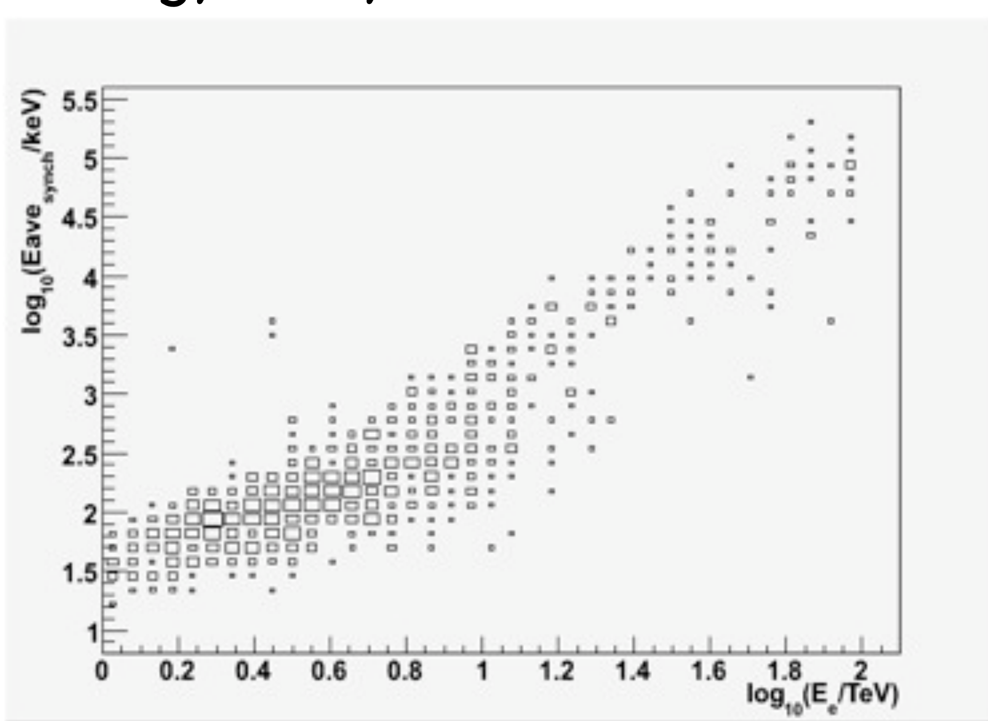


Vertical injection



Injection with 40 degree zenith angle

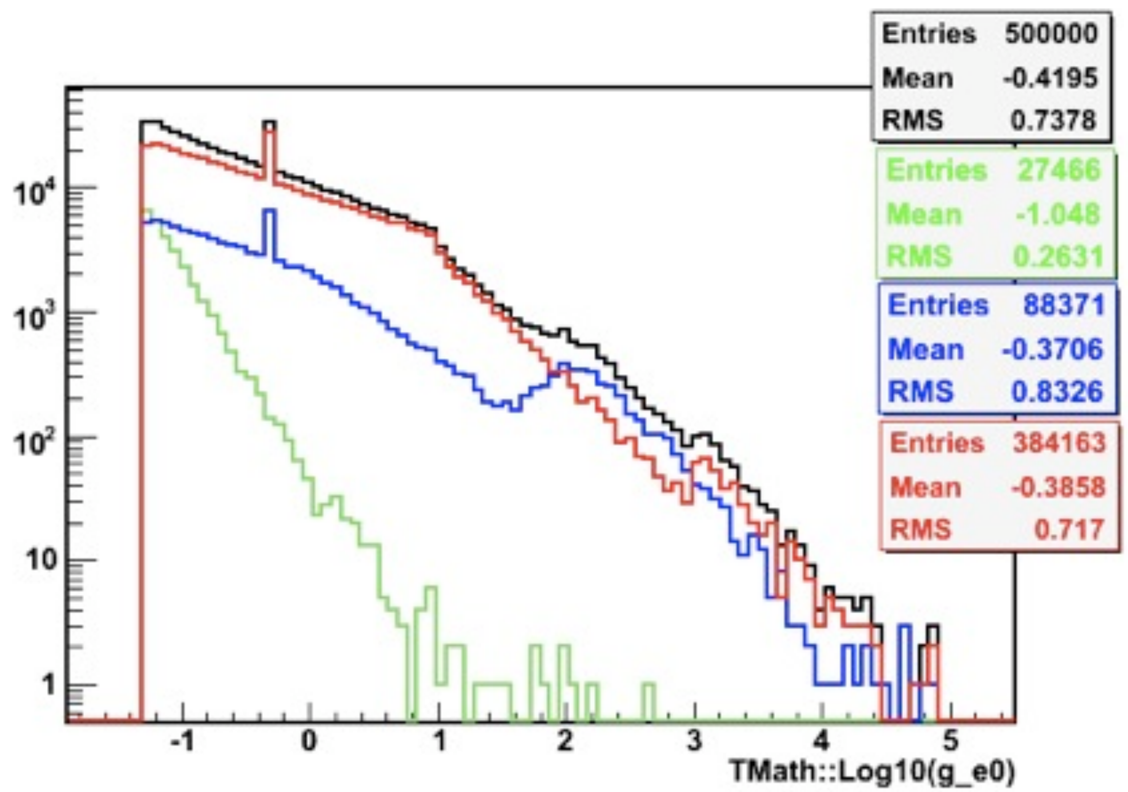
- Average energy of synchrotron radiation Vs. energy of incident electron energy

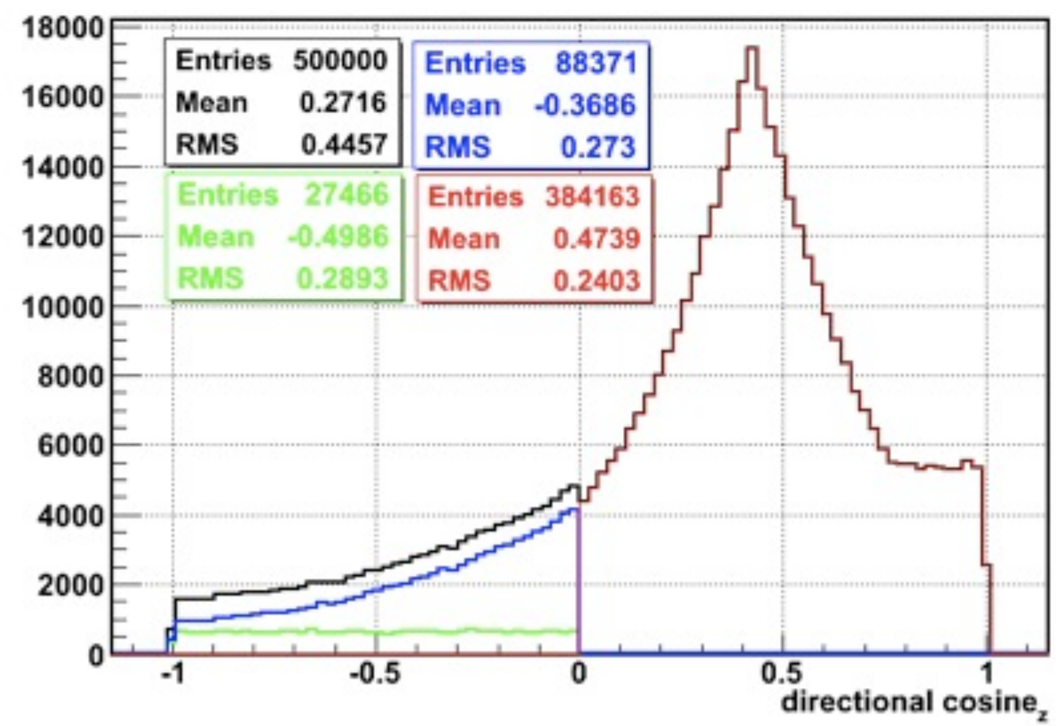


Simulation Study (4)

- Simulation study for the background γ-ray
  - Total flux within the area of detector (5.8 m^2) : 1.42820 × 10^6 [/sec]
    - Primary gamma-ray
    - Secondary gamma-ray downward
    - Secondary gamma-ray upward

}Depends on air overburden, rigidity cut-off

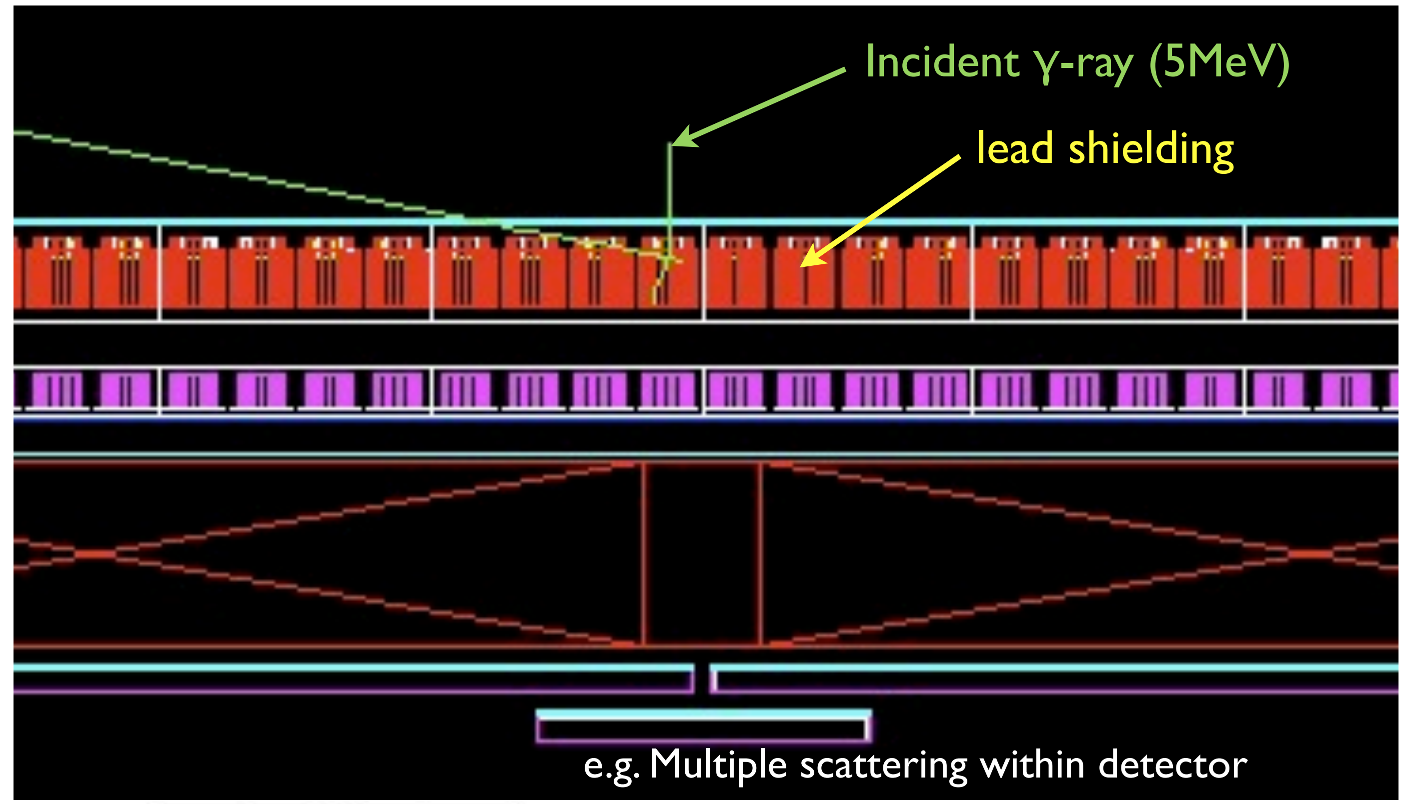


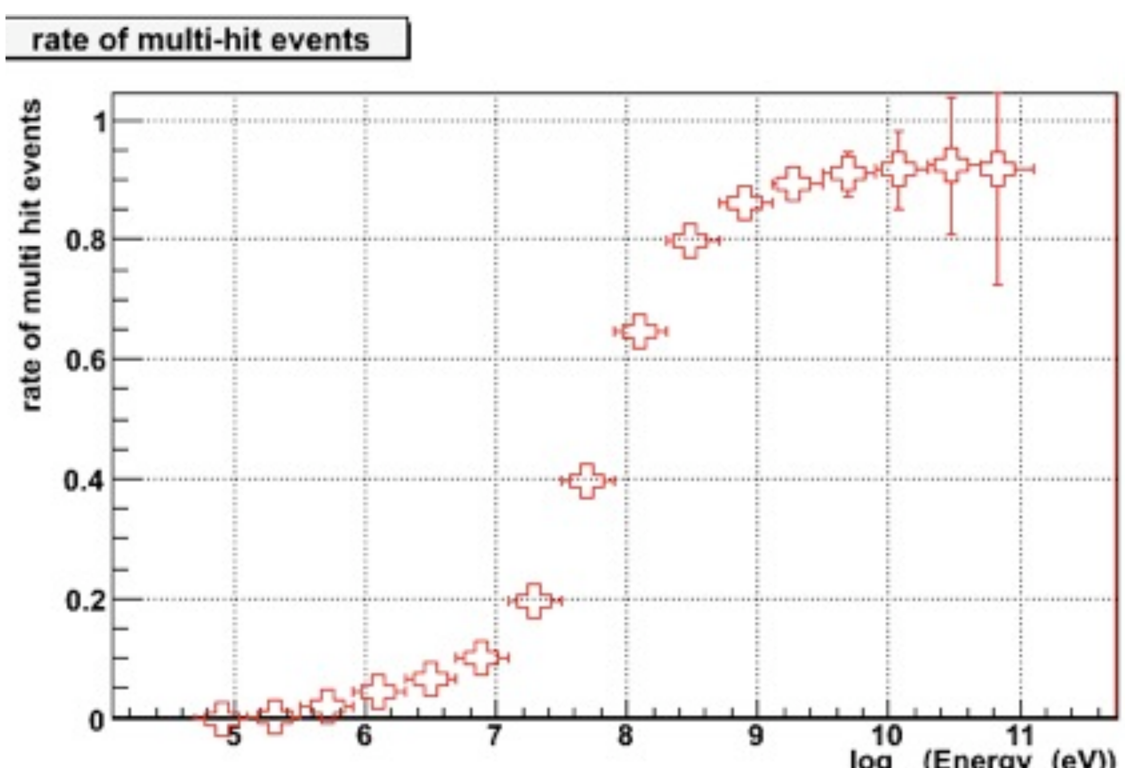


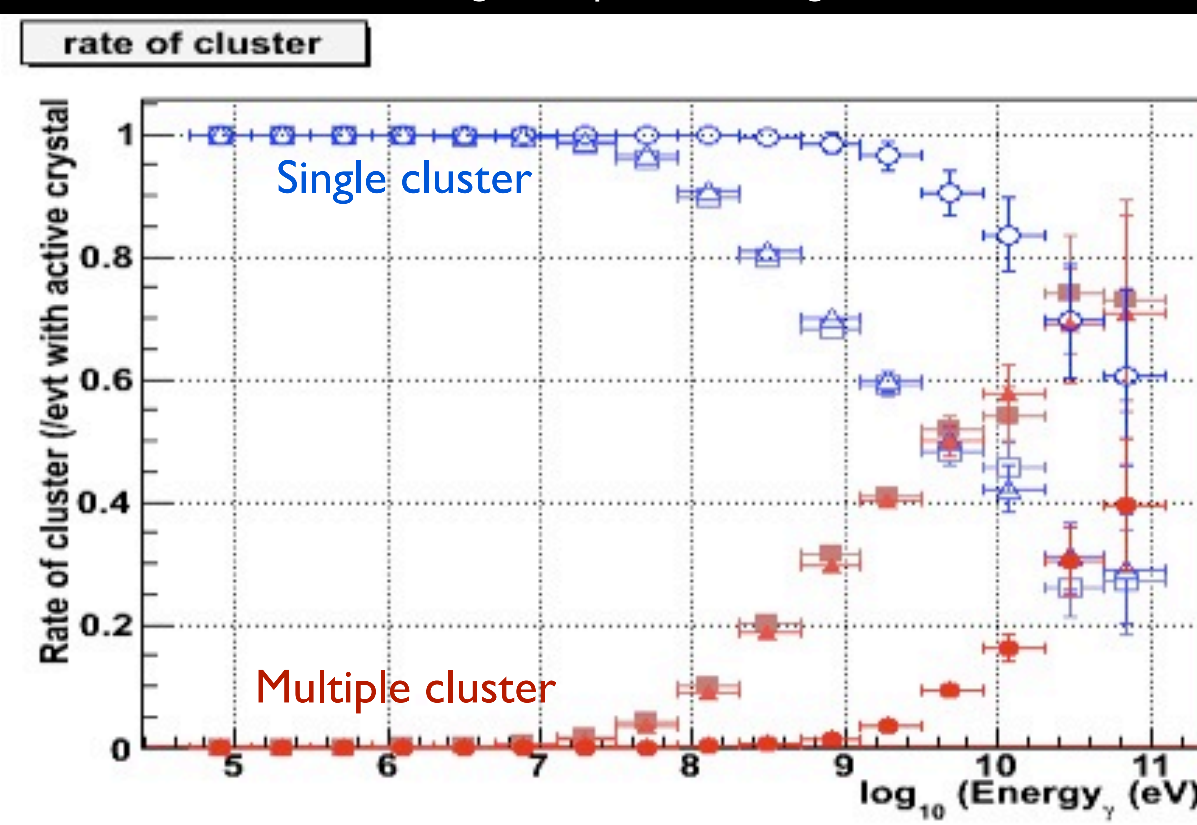
e.g. energy and zenith angle distribution generated in Geant4 simulation

Simulation Study (5)

- Multiple crystals triggered by the Compton scattering within the detector is the main background component
  - Wrap lead shielding around each PMT to reduce the multiple scattering effect



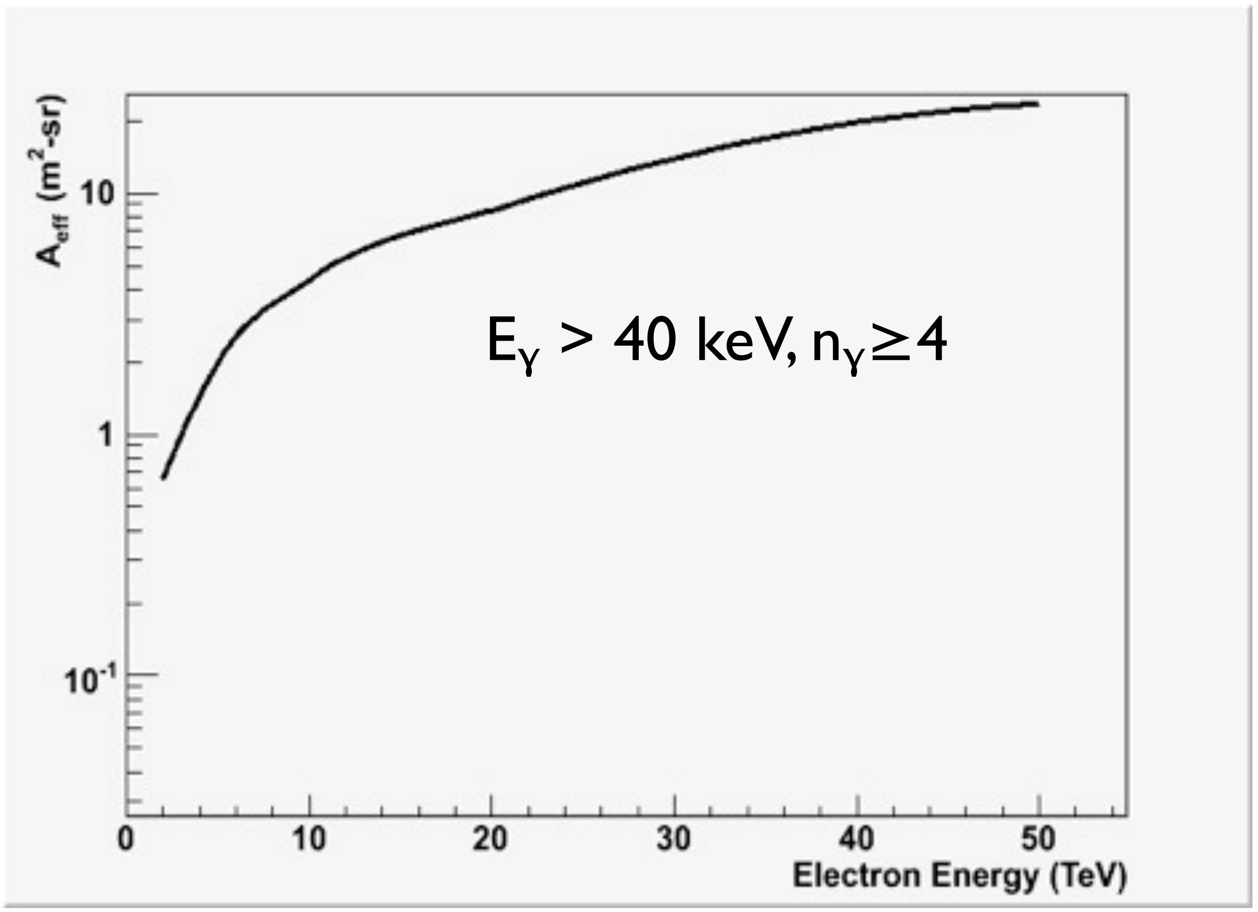




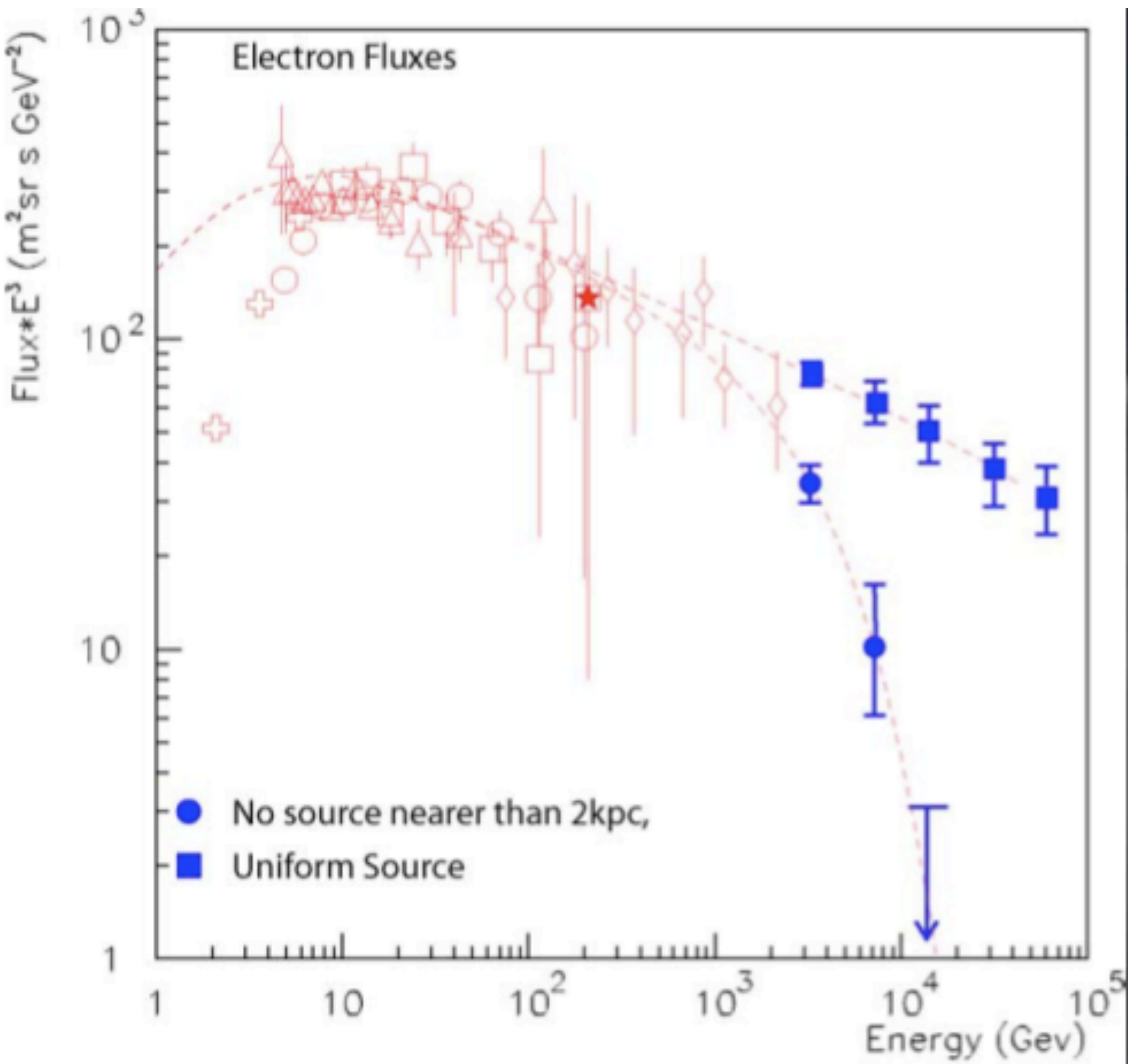
Simulation Study (6)

1. Show the effective area
 -> to show the ability of this measurement
2. Measurement possibility - depends on the shape of the spectrum

Need to show
1. Can simulate the signal
2. Background...how many electron will be arrived?



E_γ > 40 keV, $n_\gamma \geq 4$



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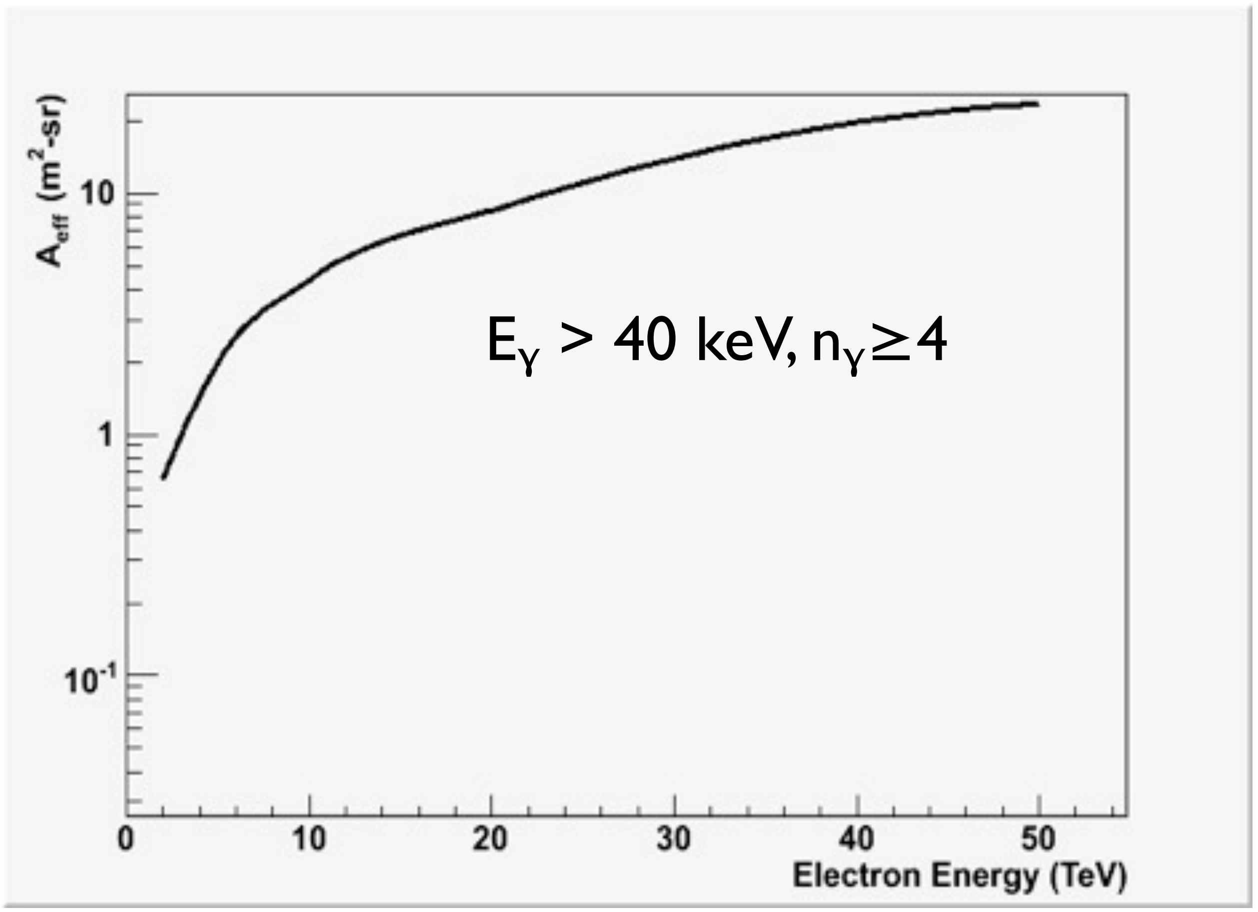
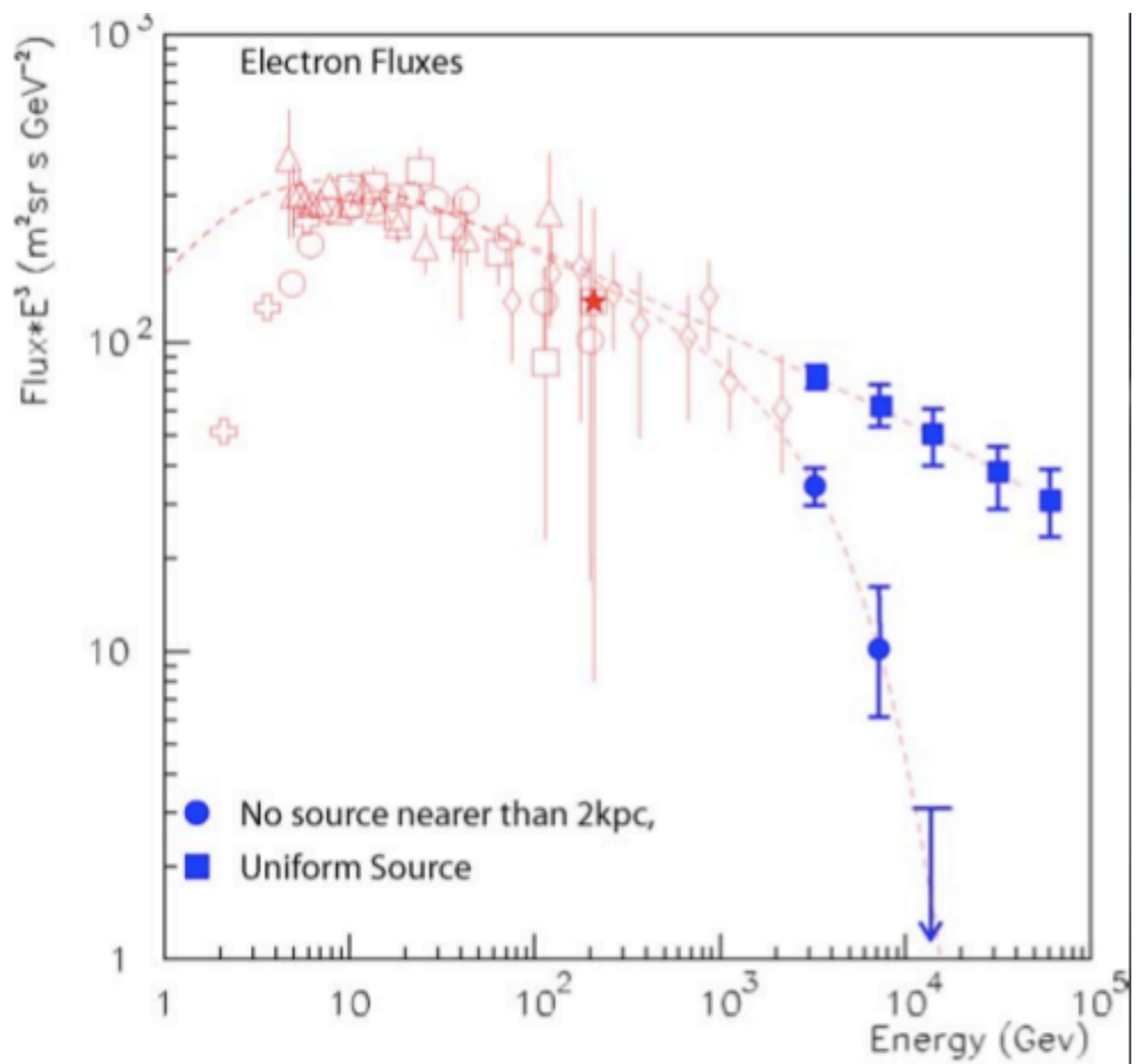




About 2 events/day above 2 TeV

Assumes $E^{-3.3}$ spectrum with no cutoff

ConUS flight (1)

ConUS flight (Spring 2009)

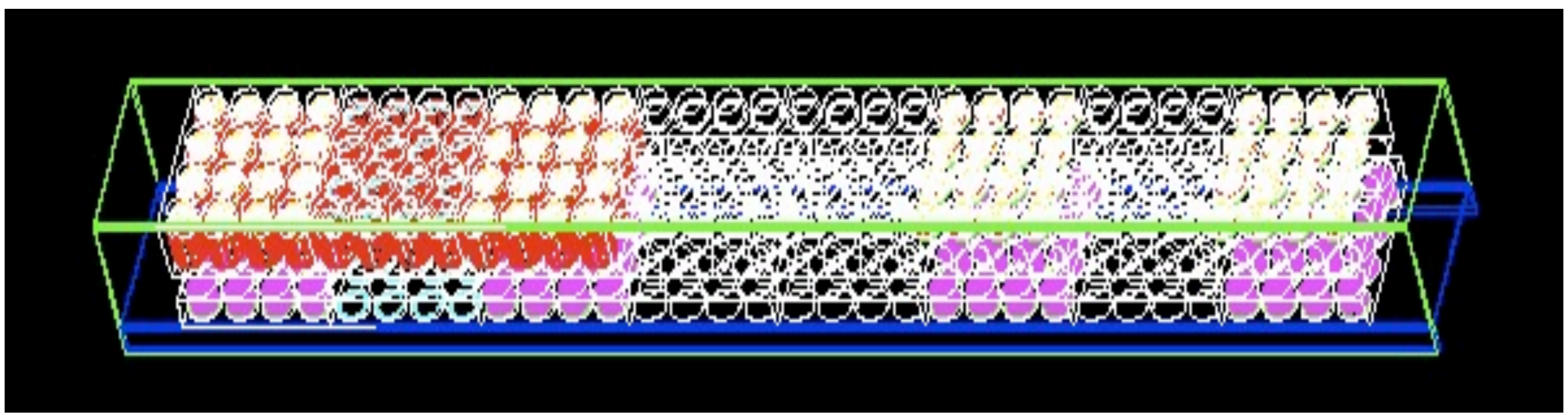
- Purpose : testing the detector at balloon environments
  - Electronics & firmware test
  - Background measurement
    - Calibration of simulation model
- Location : Fort Sumner, TX
- Flight period : < 1 day
- Instrument
  - One channel with 4 sets of crystal array (64 BaF_2 crystal + PMTs)
  - 4 veto counters (top, bottom and side veto)

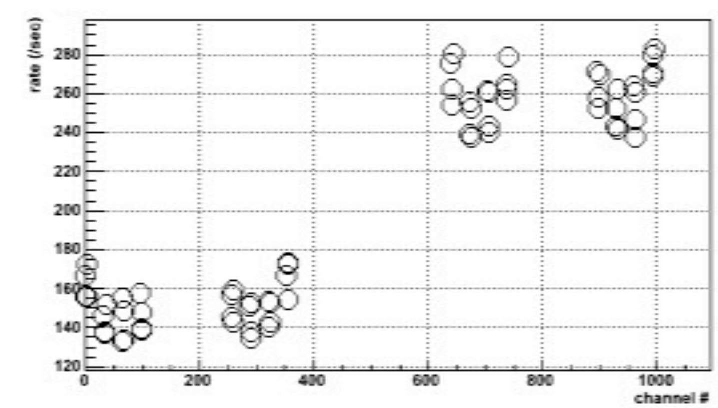
ConUS flight
(Continental US) flight

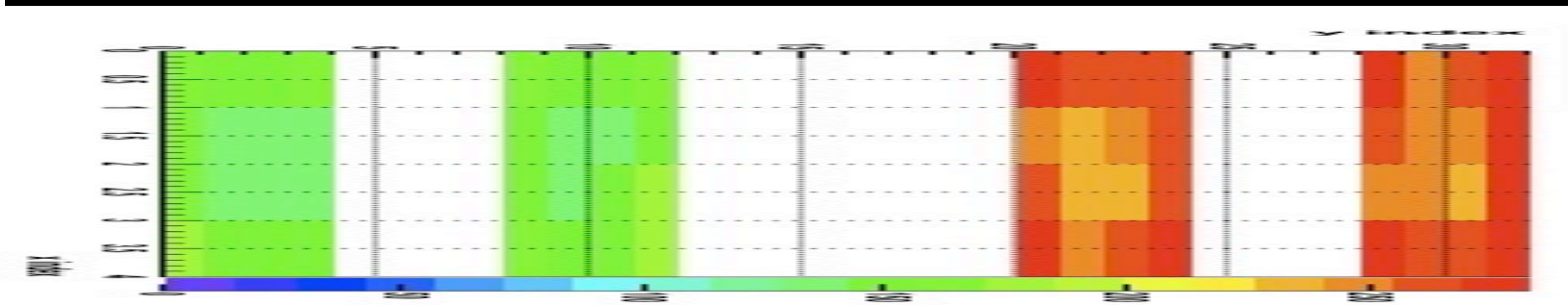
ConUS flight (2)

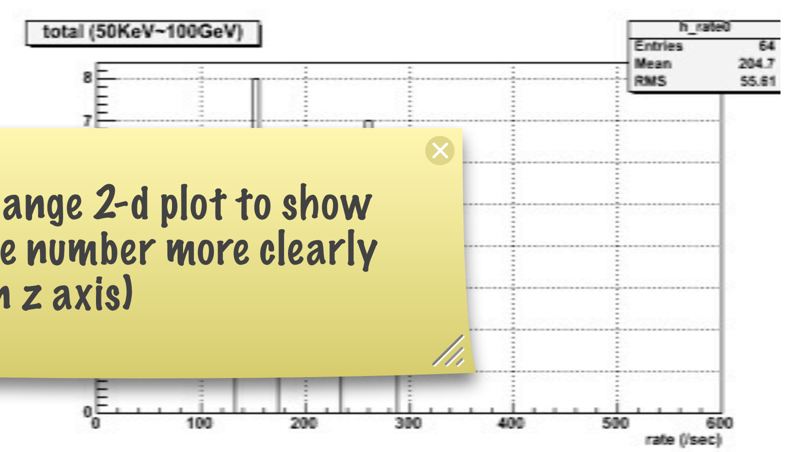
Background estimation

- Geant4 simulation (with gamma ray generator from GLAST CR generator) predicts signal rate for the gamma ray (primary + secondary) of 50 keV ~ 100 GeV would be
  - ~ 145 Hz for with lead shielding
  - ~ 260 Hz for without lead shielding



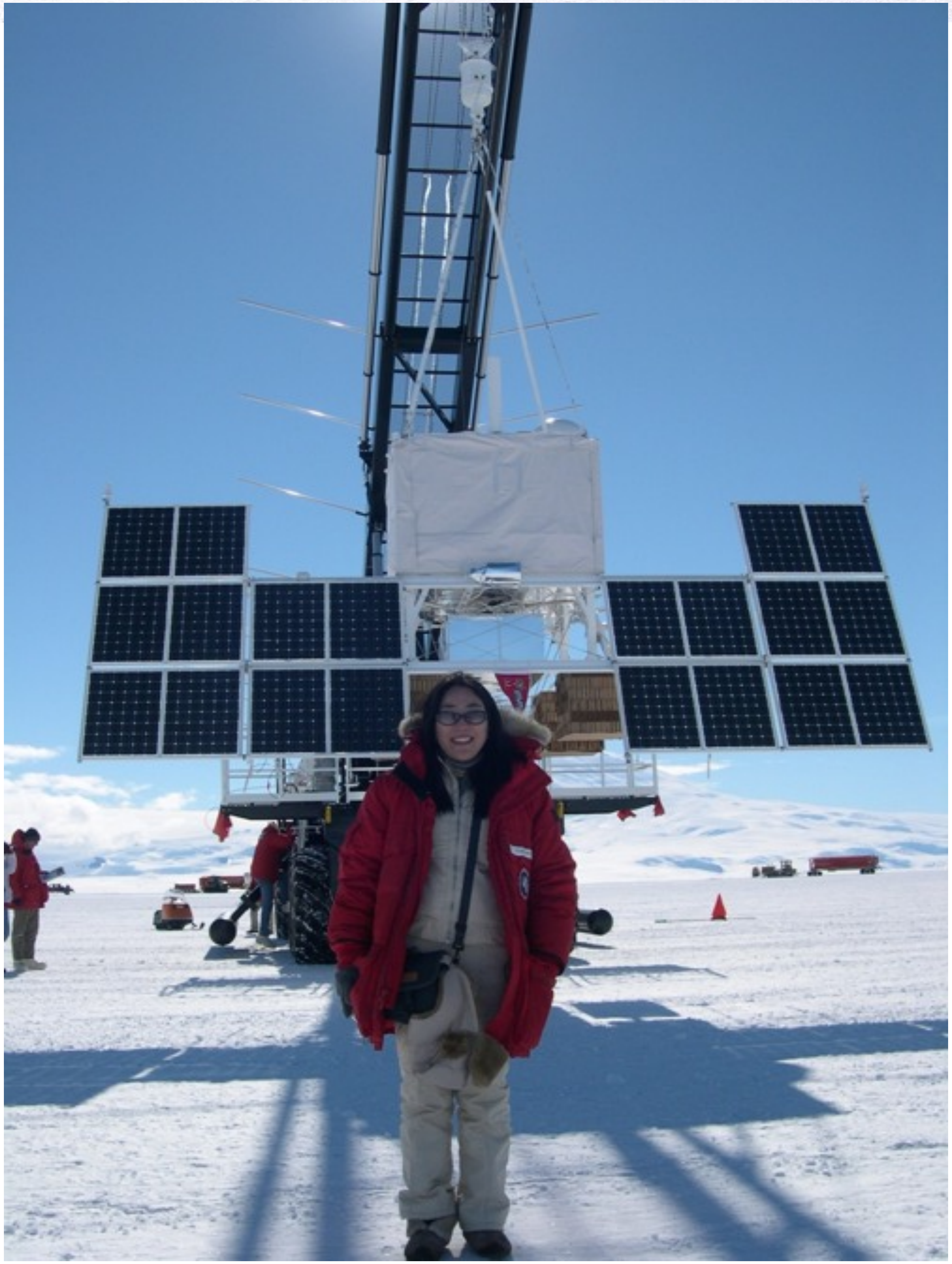






Change 2-d plot to show the number more clearly (on z axis)

flight at Antarctica



e.g. Flight of CREAM-I

Summary

- ☐ TeV electron flux is expected to reflect the distribution and abundance of nearby accelerating sources.

- ☐ The Cosmic Ray Electron Synchrotron Telescope (CREST) is designed to measure the spectrum of multi-TeV electrons through the detection of the x-ray synchrotron photons generated as the electrons traverse the Earth's magnetic field.

- ☐ Aiming for a flight in Antarctica as a long duration balloon payload during the 2010-11 season, a test flight of CREST will take place in the continental US on 2009.